

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF FISH AND GAME
BUREAU OF MARINE FISHERIES

FISH BULLETIN No. 61

Results of Tagging Experiments
in California Waters
on the Sardine
(*Sardinops caerulea*)



1945

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FOREWORD

The three papers included in this Fish Bulletin constitute a summary of the work which has been done by the Bureau of Marine Fisheries of the California Division of Fish and Game between 1936 and 1944 to measure movements and abundance of the sardine population by means of a tagging program.

As in all other phases of the sardine investigation, many members of the staff of the Bureau of Marine Fisheries have contributed to the tagging program. Dr. Richard Van Cleve, Chief of the Bureau, has given much help with the mathematical formulae and with the editing of the manuscript. In the weekly tests of efficiency of tag recoveries special credit is due to Mr. Robert D. Byers who carried out all the tests at Monterey in 1938-39. The many workmen in the reduction plants throughout the State have rendered invaluable aid through the faithful care they have given to the magnets and the collection of the tags. In many instances their keen interest in the experiments and the results obtained furnished the inspiration which carried the task through the most difficult aspects of its procedure.

The Bureau of Patrol of the Division of Fish and Game has furnished boats manned by patrol personnel from which most of the sardines have been tagged in California waters, has aided in the collection of tags recovered in the reduction plants and has given much valuable advice in solving the many problems which have developed during the progress of tagging fish, installing magnets and recovering tags.

The plant operators throughout the State have installed the magnets, which are furnished by the California Division of Fish and Game. In some instances, in order to make room for a magnet, the operators have gone to considerable trouble and expense to assure a satisfactory installation. Many fishermen have donated fish both for tagging in the ocean and for experimental studies.

We are indebted to Dr. G. E. MacGinitie of the Kerekhoff Laboratory of the California Institute of Technology for the use of the many facilities at Corona Del Mar during the construction of the floating live boxes used in the experiments measuring tagging mortality. Mr. H. M. Davis of the same institution gave many valuable suggestions and much assistance. Dr. W. F. Thompson of the University of Washington, Dr. John L. Hart of the Fisheries Research Board of Canada and Dr. John L. Kask of the California Academy of Sciences have read the manuscript and given helpful advice.

The Fisheries Research Board of Canada, the Department of Fisheries of British Columbia, the Department of Fisheries of Washington and the Fish Commission of Oregon have cooperated in this tagging program by tagging fish, by recovering tags and by testing efficiency of tag recovery methods in their respective jurisdictions. Also the Fish Commission of Oregon has permitted inclusion of records of recoveries from

Oregon taggings prior to publication by the Oregon authority. Finally, the various methods here used to analyse the tag returns have been discussed and developed in conferences held with the fisheries investigators representing these governments plus those of the U. S. Fish and Wildlife Service engaged in its South Pacific Investigations.

FRANCES N. CLARK

February, 1945

MOVEMENTS AND ABUNDANCE OF THE SARDINE AS MEASURED BY TAG RETURNS

By FRANCES N. CLARK, and JOHN F. JANSSEN, JR.

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INTRODUCTION

Sardines in California waters are marked with an internal nickel-plated tag and the tags are recovered by means of electromagnets placed in the meal lines of reduction plants (Janssen, 1937, 1938, Fry, 1937). This program was initiated in 1936 and was carried on continuously until 1942. Sufficient recoveries have been made in the eight elapsed seasons to warrant an attempt to use these returns both as a measure of the extent of the migration of the sardine population along the Pacific coast of North America and as a measure of the size of the population of fish of commercial sizes, approximately 170 mm. standard length and greater.

These experiments show that sardines move throughout their range from British Columbia to Mexico. This movement is at times rapid, since fish tagged off southern California in February and March have been retaken off British Columbia in the following July and sardines released off British Columbia in July and August have been caught off California in the succeeding December and January.

The rapidity of dispersal throughout the range is associated with the size of the fish. The largest sardines may be expected to move quickly to distant fishing grounds, whereas the smaller fish tend to remain longer in the locality where tagged or to make short migrations. These smaller fish reach more distant grounds in later years when they have grown to larger sizes.

When used to measure the size of the population, the numbers of recovered tags must be adjusted to counteract the influence of tagging mortality, shed tags and failure to recover tags. No adjustments could be made that would eliminate the effect of migrations on the number of tags returned. Because of this, all measures of total decline from season

to season represent a summation of natural mortality, fishing mortality and gains or losses due to migration or changes in availability to the fishermen. These various factors can not be measured independently.

The size of the total population could be estimated, however, from the recoveries of tagged fish during the seasons 1936-37 through 1943-44, and for this time interval a population of approximately nine billion sardines of commercial sizes is indicated. From this population the fishery took about 50 per cent each year, 4 per cent in British Columbia, Washington and Oregon, 31 per cent at San Francisco and Monterey and 15 per cent in southern California.

MOVEMENTS

Tagging Localities

The study of sardine movements by marking experiments has been made possible through the cooperation of several government agencies. The Fisheries Research Board of Canada has tagged sardines off the west coast of Vancouver Island and southward off the coast of Washington. The Department of Fisheries of Washington has marked small sardines in the bays of that State and the Fish Commission of Oregon has tagged off the coast of Oregon and northward off the Washington coast. All of these authorities have installed magnets in the reduction plants operating within their boundaries and have recovered and returned tags to the organization by whom they were released.

The Division of Fish and Game of California has marked adult and young sardines and released them in the coastal waters from San Francisco south to Magdalena Bay, Lower California. In the San Francisco-Monterey area, releases have been made as far off shore as the Farallone Islands. In southern California tagged sardines have been released along the mainland from Hueneme south to San Diego and off shore around the Channel Islands of Santa Cruz, Anacapa, Santa Barbara, Santa Catalina, San Nicolas and San Clemente.

In Mexican waters the tagging of sardines has been confined to limited areas where fish have been available at such times as the staff of the Division of Fish and Game was in Mexican waters with a research boat. Marked fish have been released along the mainland of Lower California from Cape Colnett south to Sebastian Viscaïno Bay. In addition one lot was tagged and released in Magdalena Bay.

North and South Movements

The directions of sardine migrations as shown by tag returns are illustrated in figure 1. These four maps indicate the dispersal from the four major tagging areas to distant fishing grounds. Movements between the San Diego and San Pedro fishing areas are not shown. The interchange of fish between the fisheries of British Columbia, Washington and Oregon has been reported by Hart (1936, 1937, 1938, 1939).

Small numbers of sardines have been tagged in Mexican waters during the last five years but not until 1939 was it possible to mark fish in large numbers in these waters. The returns from tagging in 1939, 1940 and 1941 indicate a movement into the southern and central California

fisheries of sardines released in Sebastian Viscaïno Bay and north of this locality.

The numbers of tagged fish released in California waters and their subsequent recoveries are given in tables 1 and 2. When sardines are tagged and released on the fishing grounds many recoveries occur within the season of tagging before the fish have had an opportunity to move to more distant grounds. To eliminate these returns, recoveries made in the same season as that in which the fish were tagged have not been included in these tables. From releases in central California 49 tags were recovered in southern California during the season of release. These recoveries are included in figure 1 and account for the discrepancy between figure 1 and table 1.

The method of recovering tags does not return every tag which enters the canning or reduction plants, but a measure of the percentage of loss has been determined as discussed in the paper "Measurement of

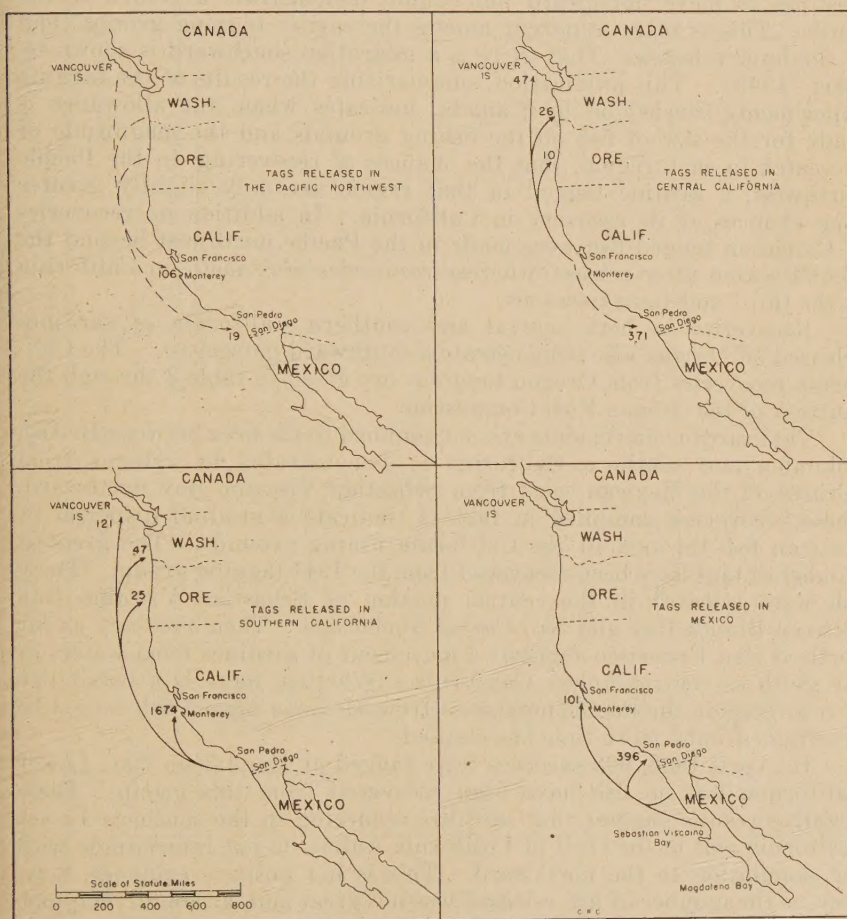


FIG. 1. Sections of the Pacific Coast of North America showing diagrammatically the major movements of tagged sardines as indicated by recoveries from June, 1935 to May, 1944.

the losses in the recovery of sardine tags". With these percentages it is possible to calculate the number of tags which would have been recovered if recovery methods had worked at 100 per cent efficiency. Tables 1 and 2 give the actual tags recovered and the number expected if 100 per cent had been recovered. The measures of recovery efficiency are listed in table 12.

Tables 1 and 2 indicate that marked fish tend to disperse to all fishing grounds. This holds true whether the sardines are released off San Francisco and Monterey or off southern California. Although some fish will be taken in the Pacific northwest in the first season following release, the proportion of recoveries on the northern grounds increases in the succeeding seasons. The time required for fish to move to more distant grounds is associated with the size of the fish when tagged as is indicated in tables 7-10.

The recoveries, shown in tables 1 and 2, suggest a tendency for sardines to move northward but cannot demonstrate a return to the south. This is more apparent among the earlier tagging groups than in the later releases. That there is a migration southward is shown by Hart (1943). This publication, summarizing the results of the tagging experiments carried on by Canada, indicates when due allowance is made for the size of fish on the fishing grounds and the magnitude of the catch in each region, that the chances of recovering, in the Pacific northwest, a sardine tagged in that region are only slightly greater than chances of its recovery in California. In addition no recoveries of Canadian tagged fish were made in the Pacific northwest beyond the second season after release, whereas recoveries were made in California in the third and fourth seasons.

Recoveries in both central and southern California of sardines released off Oregon also demonstrate a southward movement. The California recoveries from Oregon taggings are given in table 3 through the courtesy of the Oregon Fish Commission.

That sardine movements are not confined to the area between British Columbia and southern California is demonstrated by returns from releases off the Mexican coast from Sebastian Viscaïno Bay northward. These recoveries, compiled in table 4, indicate a gradual dispersal of Mexican fish throughout the California fishing grounds. The greatest number of tags have been recovered from the 1941 tagging group. These fish were released in the central portion of Sebastian Viscaïno Bay between Blanca Bay and San Carlos Anchorage. Their recovery as far north as San Francisco suggests a movement of sardines from waters as far south as central Lower California. Whether there is a possibility of recoveries in the Pacific northwest from Mexican tagged fish cannot be determined until more time has elapsed.

In April 1938, 963 sardines were tagged at Magdalena Bay, Lower California, but no fish have been recovered from this group. These negative results suggest that sardines occurring in the southern Lower California and in the Gulf of California waters do not intermingle with the population to the northward. This is not positive evidence, however, as the number of fish released was not great and, although in apparently good condition, sufficient sardines may not have survived to result in recoveries in the California fishery.

SARDINE MOVEMENTS AND ABUNDANCE

[illegible]

Location of recoveries by regions of sardines tagged off Lower California. The actual number of tags are shown and also the number of tags which would have been returned at 100 per cent recovery efficiency

Tagged		San Francisco			Monterey			San Pedro and San Diego			Total
Season	Number	Season recovered	Actual	@100%	Actual	@100%		Actual	@100%	Actual	@100%
October, 1939	4,091	1940-41 1941-42 1942-43 1943-44 Totals	1 6 3 4 14	2.1 8.6 4.7 8.0 23.4	7 4 4 15	8.8 5.3 5.6 19.7		25 16 12 54	48.2 27.2 18.6 95.4	26 29 19 83	50.3 44.6 28.6 138.5
October, 1940	6,766	1941-42 1942-43 1943-44 Totals	4 4 8	6.0 7.3 13.3	10 5 18 33	12.3 6.6 24.5 43.4		25 48 20 93	40.2 73.2 27.9 141.3	35 57 42 134	52.5 85.8 59.7 198.0
November, 1941	5,070	1942-43 1943-44 Totals	1 4 5 27	1.6 8.0 9.6 46.3	2 24 26 74	2.7 33.4 36.1 99.2		153 96 249 396	238.5 135.0 373.5 610.2	156 124 280 497	242.8 176.4 419.2 755.7
Grand totals	15,927										

TABLE 5
Number of tags recovered in the 1942-43 California fishery by lunar months from marked fish released off Oregon in July and August, 1941

Lunar month	Millions of fish caught			Tags recovered			Tags recovered per 100 million fish caught		
	San Francisco	Monterey	San Pedro	San Francisco	Monterey	San Pedro	San Francisco	Monterey	San Pedro
August 1-26	176	142		2	5		1.14	0	
August 27-September 24	197	410		8	3		4.06	1.22	
September 25-October 24	119	109	440	5	3	3	4.20	2.75	
October 25-November 22	97	156	507	3	5	1	3.09	3.21	.68
November 23-December 22	68	186	455	1	1		1.47	2.27	.14
December 23-January 20	70	122	315		6		0		
January 21-February 18	3	209	152		2	1	0	.96	

The returns from the sardine tagging experiments do indicate, none the less, a general pattern of migration north and south along the Pacific coast of North America. Superimposed on this general picture are many minor movements of certain units of the population. The results as yet only hint of these complexities but two experiments have yielded sufficient recoveries to suggest the manner in which a group of sardines will move onto the California fishing grounds.

During July and August 1941, the research staff of the Oregon Fish Commission marked and released 5300 sardines in waters off the Columbia River and northward to Gray's Harbor, Washington. No tags were recovered in the California fishery until 1942-43. Table 5 shows the number of tags recovered by regions and for each lunar month of the 1942-43 season. The table also gives the numbers of fish in the commercial catch and finally the number of tags recovered per 100 million fish caught each lunar month at each port. For the San Francisco fishery the number of Oregon marked fish per 100 million fish caught increased each month until it reached a peak in early October and then decreased until late December after which no more Oregon tags were recovered. Recoveries at Monterey are slightly less consistent but they show, in terms of the number of fish caught, an increase to a maximum in early November and then a decline through the succeeding months. San Pedro recoveries are too few to justify the drawing of conclusions. These sardines tagged off the Oregon and Washington coasts illustrate the manner in which sardines from the north move onto California fishing grounds.

TABLE 6

Number of tags recovered in 1942-43 in the southern California fishery by lunar months from marked fish released off the Mexican coast in November, 1941

Lunar month	Millions of fish caught	Tags recovered	Tags per 100 million fish caught
September 25-October 24-----	440	13	2.95
October 25-November 22-----	507	45	8.88
November 23-December 22-----	455	54	11.87
December 23-January 20-----	315	23	7.30
January 21-February 18-----	152	17}	11.32
February 19-March 21-----	7	1}	

Similar but reverse movements from the south are demonstrated by the group of 5070 fish released in Mexican waters in November 1941. The 153 recoveries in southern California in 1942-43 from this tagging group are numerous enough to yield a measure of the proportion of tags recovered each succeeding lunar month. These figures, together with the number of fish caught, are given in table 6. The number of Mexican tagged sardines on the southern California fishing grounds increased from the beginning of the season until early December and then, in terms of tags per million fish caught, showed little change for the succeeding three months.

The recoveries from sardines tagged and released throughout the range of the sardine population from Mexico to Canada indicate that marked sardines will gradually disperse over this range. The rapidity of this dispersal is correlated with the size of the fish. Larger fish travel

greater distances and as each fish increases in size and age it moves to more distant grounds. This was demonstrated by Janssen (1938).

Differential Movements According to Size

The length frequency distributions of sardines sampled from the commercial catches at the various sardine fishing localities along the Pacific Coast indicate that the population to the north is composed of a greater proportion of large fish than the population farther south. In figure 2 are shown the season length frequency distributions of fish sampled from the commercial catches at the important Pacific Coast sardine ports during one season. Frequency A represents the Oregon, Washington and British Columbia data combined for the 1939 season.

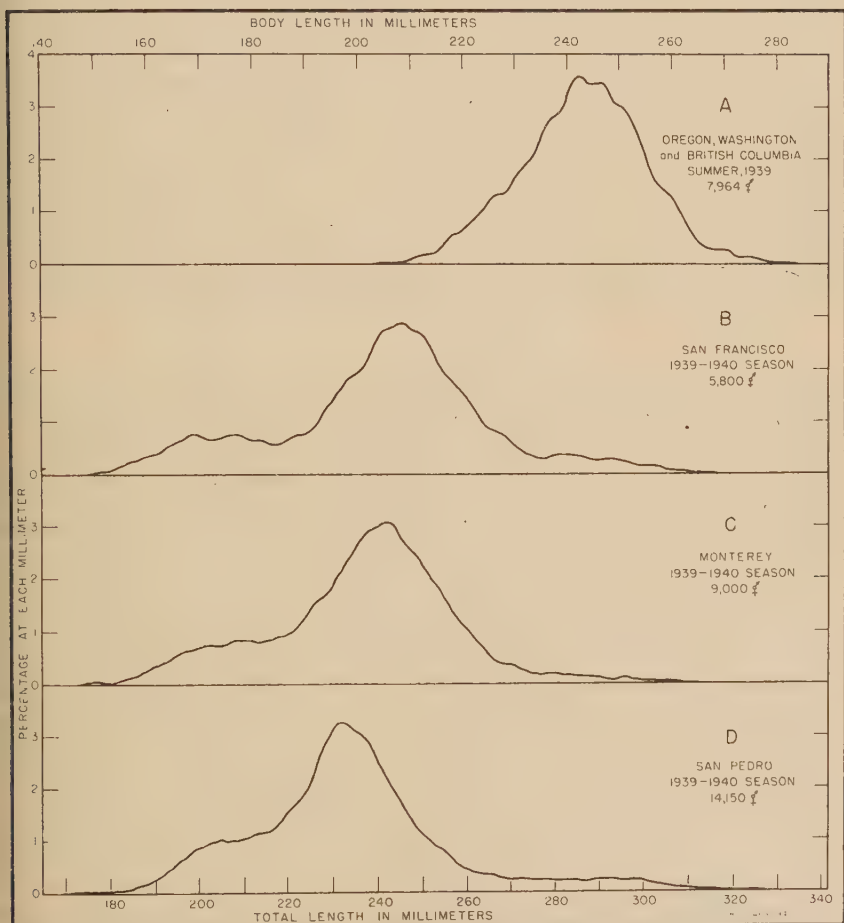


FIG. 2. A comparison of the season length frequency polygons of sardines sampled from the commercial catches at the important sardine ports on the Pacific Coast. The frequency for the fishery north of California is included by permission of the Fish Commission of Oregon, the United States Fish and Wildlife Service, the Fisheries Research Board of Canada and the Provincial Fisheries Department of British Columbia.

The San Francisco, Monterey and San Pedro 1939-1940 frequencies are shown as B, C, and D, respectively. Hart (1943) has demonstrated that the largest sized sardines are as abundant on the California fishing grounds as on the northern grounds but they are overshadowed in the California catch by a greater number of small fish.

North of California the sardine fishing season starts in June or July and continues as far into the fall or winter as weather and availability of fish permit. In central California the season lasts from August 1st to February 15th of the following year. In southern California the sardine season starts on October 1st and ends the following March 1st. These seasons refer to the fishery for canning and reduction only.

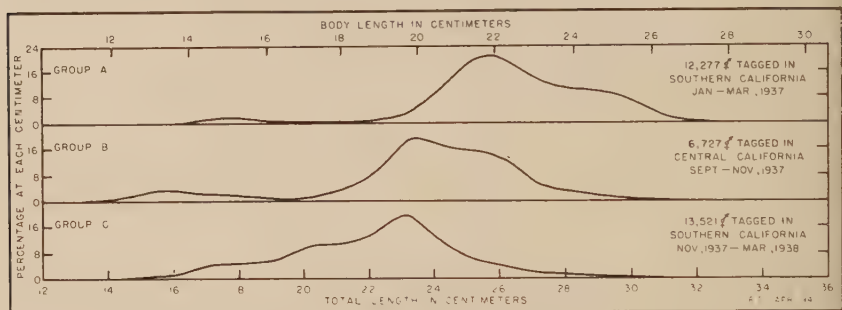


FIG. 3. Length frequency polygons of the three groups of tagged sardines used for demonstrating the differential movements of the fish according to size.

For the purpose of demonstrating the differential movements of sardines according to size, three groups of tagged fish are available. For each group sufficient time has elapsed since tagging to yield returns for three fishing seasons including the season of release. Comparisons are made of the sizes of the tagged fish which were caught in succeeding fishing seasons in the several sardine fishing areas along the Pacific Coast. Figure 3 shows the length frequency polygons of the fish comprising the three groups. Group A consists of 12,277 sardines tagged along the southern California coast from January through March of 1937. These fish were tagged during the so-called "winter fishery" at which time the larger sizes appear on the fishing grounds in their greatest numbers. The 6,727 sardines which compose group B were tagged during September, October and November of 1937 in the Monterey-San Francisco area. All of these fish were released during the fall fishery before the normal influx of larger sizes. This has resulted in a mode at a lower size class than for group A. Group C consists of 13,521 sardines marked during the succeeding four months (December 1937 through March 1938) in southern California waters. The majority of these fish were of medium size. A good many of them were tagged before the occurrence of the larger sizes in the winter fishery. Some effort was made to tag the smaller sizes which appear in the commercial catch. Thus a few of the fish were obtained from boats which fish for live bait and are primarily interested in the smaller sardines. The majority of the fish, however, were obtained from the larger boats fishing for the canneries and reduction plants.

TABLE 7

Length frequencies of sardines tagged off southern California from January to March, 1937, compared with the frequency distributions of these fish recovered during the season of tagging and in succeeding seasons in various localities. All lengths represent total length when tagged, read to the nearest centimeter.

Total length, cm.	Number of fish when tagged	Recovered Southern California				Recovered Central California			Recovered British Columbia, Washington, Oregon		
		1936-1937	1937-1938	1938-1939	1939-1940	1937-1938	1938-1939	1939-1940	1937-1938	1938-1939	1939-1940
14	1										
15	2										
16	14										
17	195			1			2				
18	220				1		4	1			
19	85		1	1							
20	52	1				1					
21	79	1				1					
22	161	4	1			2	2				
23	419	9	2	1		10	5				
24	1,332	24	5	2		33	10	1	3	4	1
25	2,425	44	8	1		49	12	1	3	5	1
26	2,332	36	3	1		34	5	2	3	5	2
27	1,644	20	3			14	3	1	6	8	2
28	1,245	18				11	2		8	5	1
29	1,123	23				4	3		6	5	
30	686	7				4			1		
31	222	2									
32	36										
33	3										
34	1										
35											
Totals	12,277	189	23	7	1	163	48	6	30	32	7

TABLE 8

Length frequencies of sardines tagged off central California from September to November, 1937, compared with the frequency distribution of these fish recovered during the season of tagging and in succeeding seasons in various localities. All lengths represent total lengths when tagged, read to the nearest centimeter.

Total length, cm.	Number of fish when tagged	Recovered Central California			Recovered British Columbia, Washington and Oregon	
		1937-38	1938-39	1939-40	1938-39	1939-40
13	17					
14	95					
15	244					
16	266			1		
17	162		1			
18	101		1			
19	66		2			
20	110			1		
21	248	5	4			
22	708	11	7	3		
23	1,181	35	11	2		
24	1,002	51	7	1	1	2
25	1,018	78	8	1	8	3
26	790	61	4	3	6	1
27	367	29	3	1	3	2
28	191	20	2		1	1
29	98	5			1	
30	42	3				
31	16					
32	3					
33						
34	2					
35						
Totals	6,727	298	50	13	20	9

TABLE 9

Length frequencies of sardines tagged off southern California from November, 1937, to March, 1938, compared with the frequency distribution of these fish recovered during the season of tagging and in succeeding seasons in various localities. All lengths represent total length when tagged, read to nearest centimeter.

Total length, cm.	Number of fish when tagged	Recovered Southern California			Recovered Central California		Recovered British Columbia, Washington, Oregon	
		1937-38	1938-39	1939-40	1938-39	1939-40	1938-39	1939-40
13	4							
14	8							
15	95		1					
16	266		2		3			
17	594	2	6	3	4	2		
18	690	1	10		9	6		
19	878	8	16	4	15	16		
20	1,367	19	26	4	33	21		
21	1,508	53	20		33	21		1
22	1,959	89	10	3	61	17		
23	2,634	113	18	2	91	18		
24	1,563	43	6	1	36	8	2	2
25	817	17	3		11	6	2	1
26	537	8	4		4	1	3	3
27	274	1	1		3		1	
28	187	2	2		2			
29	85						1	
30	42							
31	11							1
32	1							
33	1							
Totals	13,521	356	125	17	305	116	9	8

Each of the three groups of fish is treated separately and the tag returns are followed through successive seasons in the various regions where there is a commercial sardine fishery. San Diego and San Pedro have been combined as the southern California region. The San Diego fishery is sporadic and the yearly landings are small. Recoveries at Monterey and San Francisco have been combined into the central California region as the fishing grounds of these two areas overlap. Few tags have been recovered in any individual port in Oregon, Washington or British Columbia because the sardine landings are small. Therefore the tags recovered in these three localities have been combined to make the numbers great enough to indicate trends.

The length frequencies of the three groups under consideration are compared with the frequency distributions of the fish recovered in succeeding seasons on the different fishing grounds in tables 7-9. The length frequencies of recovered fish represent the lengths of the sardines at the time they were tagged. The lengths of the tagged fish at the time of recapture are unknown.

For all three groups there is a proportionate decrease in the recoveries of the larger fish in each succeeding season on the fishing grounds where released. This indicates that the largest fish are the first to move away from the area where released. On the other hand, the largest fish are the first to be recovered in the Pacific northwest and the central California recoveries occupy an intermediate position.

These groups indicate the nature of the northward movement of sardines but do not furnish a measure of southward movements according to size. Group C, released in central California, did not yield

sufficient recoveries in southern California during succeeding seasons to indicate size differences. The Oregon, Washington and British Columbia authorities do not measure the sardines they tag, therefore, no direct comparison can be made between sizes of fish recovered on different California fishing grounds from lots of tagged fish released to the northward.

Two groups marked in central California in 1940 and 1941 give indications of the nature of the movements to the southern California

TABLE 10

Length frequencies of sardines tagged off central California in October 1940, compared with the frequency distribution of these fish recovered during succeeding seasons in central and southern California. All lengths represent total length when tagged, read to the nearest centimeter.

Total length, cm.	Number of fish when tagged	Recovered					
		Southern California			Central California		
		1941-42	1942-43	1943-44	1941-42	1942-43	1943-44
15	16						
16	120				5	1	
17	1,017	11	15	1	54	13	7
18	3,404	41	28	5	255	52	25
19	3,287	14	11	3	237	54	16
20	1,077	5	2	1	58	18	6
21	247	1	1		8	3	1
22	246		1		3	4	
23	375				10	7	1
24	159					2	
25	68				1		
26	16						
27	4						
28	1						
29	1						
30	1						
Totals	10,039	72	58	10	631	154	56

TABLE 11

Length frequencies of sardines tagged off central California in August and September, 1941, compared with the frequency distribution of these fish recovered during succeeding seasons in central and southern California. All lengths represent total length when tagged, read to the nearest centimeter.

Total length, cm.	Number of fish when tagged	Recovered			
		Southern California		Central California	
		1942-43	1943-44	1942-43	1943-44
16	15				
17	68				1
18	159	2	1	5	2
19	394	6		7	5
20	570	5		8	2
21	748	5	1	19	11
22	1,180	12	4	23	7
23	1,497	9	1	24	18
24	812	3	2	16	4
25	166	1		3	2
26	34				1
27	8				
28	1				
29	3				
Totals	5,655	43	9	105	53

fishing grounds from central California. The length frequencies of these fish when tagged are given in tables 10 and 11 and also the size distributions of the recoveries. The tables show a definite southward movement of some of the sardines released in central California and suggest that a greater proportion of the smaller sizes have made this southward migration. For the group tagged in 1940, 72 per cent of the recoveries in southern California during the first season after tagging were less than 19 cm. when tagged. For the same season in central California only 50 per cent of the recoveries were of these smaller sizes. During the second season after tagging, 74 per cent of the southern California recoveries were less than 19 cm. when tagged but only 43 per cent of the central California recoveries were composed of these smaller sizes. For the group released in 1941, in the first season 30 per cent of southern California recoveries were less than 21 cm. and 19 per cent of the central California recoveries. In the second season recoveries are too few to justify comparisons. Tests of significance of these percentages gave P values of less than 0.001 for the group tagged in 1940 and of 0.1 for the group tagged in 1941.

ABUNDANCE

Methods

If tag returns are to be used as a measure of abundance of the population, consideration must be given to the sources of error which may invalidate the results. The number of tags that will be recovered year by year is affected by the following factors: The number of fish which die as a result of the tagging procedure, the number of tags which are shed after tagging, the number of tags which are not returned due to inefficiency in recovery methods, the rapidity with which marked fish are dispersed throughout the population, natural mortality and fishing mortality. This is a formidable array of factors but if the influence of the first four can be eliminated, tag returns may be used to measure natural and fishing mortality and hence size of population. Fishing mortality as used herein means the proportion of the population that would be taken by fishing operations were there no loss from natural causes, and natural mortality the proportion of deaths due to natural causes if no fishing were carried on.

For the sardine investigations studies have been made of the efficiency of recovery methods, of the proportion of tags shed and of tagging mortality. The details of these studies are set forth in the succeeding reports of this publication. The following discussion is confined to the application of these corrections to the tag returns.

Efficiency of Recovery

As has been discussed elsewhere, sardine tags are recovered by electro-magnets placed in the meal lines of many of the reduction plants operating along the Pacific Coast. These magnets do not retain all the tags which pass over their surface. Some tags become lost in the machinery of the plants and never reach the magnets, others are lost after the magnets have been cleared but before reaching the hands of the investigators. A measurement of these losses has been made for all ports where sardines are processed and the methods used in California

are given in detail in the report, "Measurement of losses in the recovery of sardine tags."

The table of port efficiencies as summarized in that report gives the percentage of recovery efficiency for all plants with magnets at each port in California for 1938-39 and 1939-40. From these values the number of tags per ton was calculated at a given port for the plants with magnets and this number multiplied by the total number of tons processed at that port. This gave the theoretical total number of tags which would have been recovered in each port within a season if all meal had passed over magnets and if recovery methods had been 100 per cent efficient. The ratio

$$\frac{\text{theoretical number of tags}}{100\%} = \frac{\text{actual number of tags}}{x\%}$$

gives the percentage efficiency for the recovery of tags from the total tonnage processed in each California port. This we term region efficiency. For the seasons 1936-37 and 1937-38 less detailed tests of efficiency of recovery were made. From the data available, however, the region efficiency has been approximated, and for the seasons 1940-41 to 1943-44 detailed calculations have been carried out.

TABLE 12

Percentage efficiency of recovery of sardine tags by region and by season

Season	Region of recovery						
	British Columbia	Washington	Oregon	San Francisco	Monterey	San Pedro	San Diego
March, 1936				Large tags		13	
1936-37				31	39	34	49
1937-38	72	43	18	42	50	45	60
1938-39	65	43	55	52	64	47	33
1939-40	70	72	30	44	58	36	
1940-41	73	50	30	57	66	57	49
1941-42	47	77	31	74	84	68	45
1942-43	40/70*	50	31	73	81	70	45
1943-44	40	45	30	75	77	75	
				Small tags			
1937-38				20	47	40	
1938-39			49	34	61	40	
1939-40		61	13	39	55	32	
1940-41	69	43	13	47	62	52	45
1941-42	41	65	25	70	79	61	40
1942-43	35/65*	45	25	65	75	64	40
1943-44	40	40	25	50	72	71	

* For tags recovered in plants operating on the west coast of Vancouver Island the smaller percentage value was used and for plants operating in northern British Columbia the larger.

Methods similar to those used in California have been applied to the tag recoveries in the regions north of California. The efficiencies thus calculated are published here through the courtesy of the Fisheries Research Board of Canada, the State of Washington Department of Fisheries and the Fish Commission of Oregon. The region efficiencies of tag recovery for the entire tonnage of sardines processed along the Pacific Coast of North America north of Mexico are approximated by regions for large and for small tags in table 12. In this table the efficiencies are given by seasons which cover the time interval, June 1 to the

succeeding May 31. This includes the summer fishery to the north with the immediately succeeding fall and winter fishery in California. These efficiency of recovery values have been used to calculate the number of tags which would have been recovered from each tagging lot if recovery had been 100 per cent efficient.

Tagging Mortality

A measure of the average number of fish which die as the result of tagging and of the number which shed their tags was obtained by holding tagged fish in a floating "live box." The details of these experiments are given in the report, "The effect of internal tags upon sardines." Because we are interested in the number of fish which survived tagging and did not shed their tags, the losses from death and shedding are grouped under the term tagging mortality. The "live box" experiments indicate that among small sardines (fish less than 18.5 cm. total length) the minimum tagging mortality is about 50 per cent, the average 60 per cent and the maximum 80 per cent. For fish larger than 18.5 cm. the values are, minimum 20 per cent, average 40 per cent, and maximum 70 per cent.

The experiments on holding tagged fish and the returns of tags from different lots of sardines released in the ocean show, however, that tagging mortality varies greatly from lot to lot. Under the best conditions, it is sufficient to require the application of a correction factor to the original number of fish tagged. The more accurate this correction factor is, the more accurately we can determine the number of effective tags resulting from each tagging lot released.

To obtain a correction factor the first step was the determination of those tagging lots from which sufficient fish had survived to justify their use as a measure of population size. This was done by selecting from all tagging lots only those groups which after being out for three seasons had returned tags in the second and third season. This eliminated those lots from which no tags or only one or two were recovered and left 66 lots released between March, 1936 and August, 1938. These groups comprised 41,645 tagged fish from which 1439 tags, or 2.9 per cent, were recovered in the second and third season after tagging. From these values the standard deviation of the point binominal was calculated from the formula $\sigma = \sqrt{n \times .971 \times .029}$, where n represents the number of fish in a tagging lot (Pearl, 1940, pp. 334-339). Those groups which did not return 2.9 per cent of the total number of fish tagged in the lot minus 2.58σ were discarded on the theory that tagging mortality had been too great to yield adequate returns. This test eliminated 12 more of the tagging lots. Fish tagged subsequent to August, 1938, were submitted to this same test before inclusion in the calculations.

The assumption that the failure to recover tags from a given lot is due to excessive tagging mortality is based on the fact that in most instances those lots which returned few tags were those observed to be in poor condition at the time of release. In addition, as the tagging program progressed, and more skill was acquired in handling fish prior to and during the tagging process, fewer and fewer lots were eliminated.

After selecting the tagging lots which could be used as a measure of population abundance there still remained the determination of tagging

mortality for these groups. It would be possible to use the average tagging mortality of 40 per cent for large and 60 per cent for small fish. The great difference between lots makes desirable, however, some individual measure for each. The method of sardine tagging is such that as a rule 500 or more fish are tagged in each lot. Early in the history of the investigation it was noted that more tags were recovered from the first two or three hundred fish tagged than from the later hundreds. Thus it appears that tagging mortality is accumulative within each tagging lot. This may result from several causes. Holding the fish in a "live tank" during tagging and continually dipping into this tank weakens the fish. Those held the longest are in the weakest condition

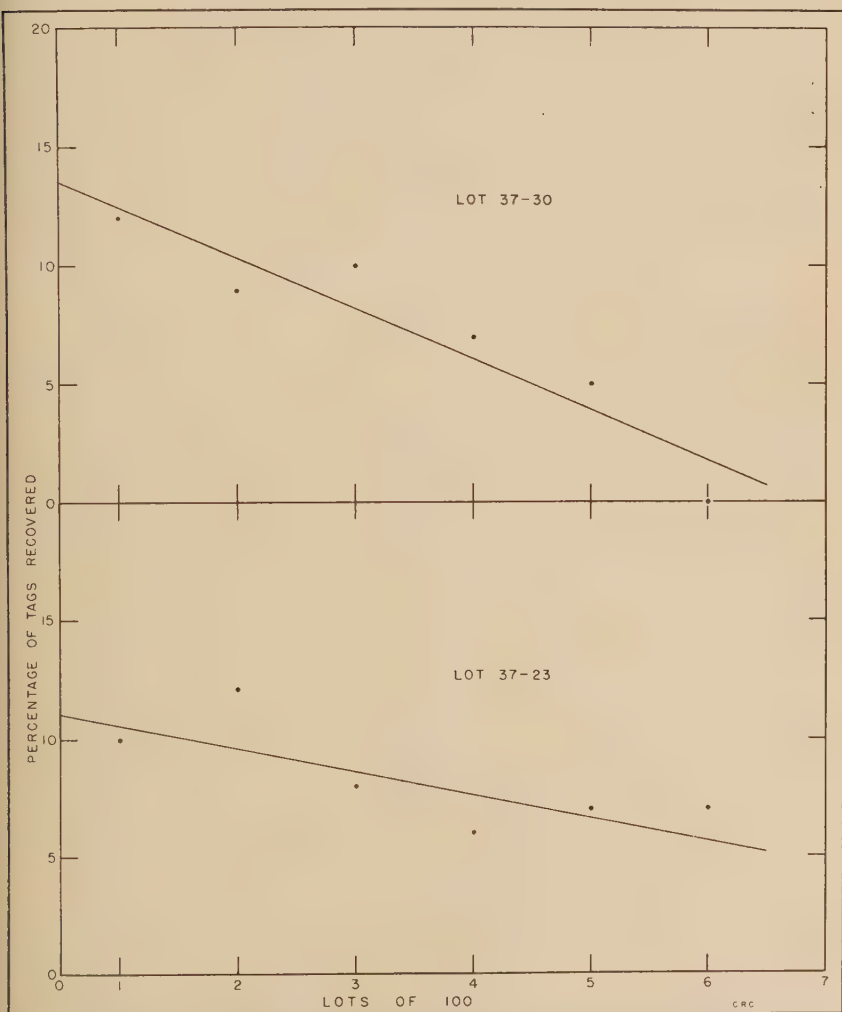


FIG. 4. Percentage of tags recovered from each 100 sardines tagged for two lots of fish. The upper graph shows a more rapid decline in the percentage of tags recovered from each 100 fish tagged than does the lower graph. The straight lines were fitted by the method of least squares.

when released. As a rule fish are tagged and released at a fixed spot and as the process continues more and more predators collect. Finally as fatigue increases the tagging crew probably is not as careful and at the end the fish are not handled as skillfully as at the beginning of a tagging interval.

This decline in the proportion of tags recovered from each succeeding hundred of a tagging lot is shown in figure 4. In this figure the upper graph indicates a greater decline in the percentage of tags recovered per 100 fish tagged than does the lower.

The accumulation of tagging mortality within a tagging group has been used to measure the tagging mortality of each group involved in this study of population abundance. After tags had been released for two or more seasons, compilations were made of the percentage of tags recovered from each 100 fish in the lot. To the values of percentage of tags recovered from each 100 fish tagged a straight line was fitted by least squares. The intercept of this line, the point where tagging began, gives the percentage of tags which would have been recovered had there been no accumulative tagging mortality. This percentage multiplied by the number of fish tagged gives the number of tags which would have been recovered had tagging mortality not had an accumulative effect. Then

$$\frac{\text{actual number of tags recovered}}{\text{theoretical number of tags recovered}} = \frac{\text{number survived}}{\text{total tagged}}$$

Thus the variation in tagging mortality can be measured for each tagging lot. For the two lots shown in figure 4 that in the upper graph had a mortality of 43 per cent and that in the lower graph 25 per cent. The results of this method are interesting in that they give greater tagging mortality rates for those groups which were noted as being in poorer condition at the time of release. Also those groups which were tagged under the most favorable conditions showed the lowest values for tagging mortality.

This procedure does not take into account, however, the evident fact that a certain number of fish would have died as the result of tagging in addition to the loss measured by the accumulative effect of tagging mortality. In other words, a minimum tagging mortality is always suffered by each tagging group. This minimum for sardine tagging has been assumed to be the minimum measured by the "live box" experiments, 20 per cent for large fish and 50 per cent for small. This minimum was combined with the tagging mortality measured by the decline in returns per 100 fish tagged and a total tagging mortality assigned by adding the percentage minimum mortality to the percentage mortality accumulating during the tagging of a given lot and subtracting from this sum the product of the two percentages divided by 100.

As a rule no tagging lot comprised more than a few hundred fish and returns over a period of years from such small numbers are too few to be reliable. To overcome this difficulty tagging lots released in one locality during a time interval of two months or less were combined into tagging groups. The groups used in this study are given in table 13 with the total tagging mortality, the number of sardines tagged and the number of effective tags remaining after the tagging mortality was deducted.

TABLE 13

Tagging groups used in the study of population abundance for the sardine showing the number of fish tagged, the tagging mortality and the number of effective tags

Group	Date	Locality	Mortality percent-age	Number tagged	Number of effective tags
36-1, -2	March-April, 1936	Southern California	20.00	964	771
36-9, -10	November, 1936	Southern California	62.16	1,673	633
37-7, -10 to -15, -19, -21 to -24	February-March, 1937	Southern California	38.75	7,495	4,591
37-26, -27	May, 1937	Southern California	26.18	787	581
37-30, -32, -34 to -36	September-October, 1937	Central California	40.98	2,760	1,629
37-42 to -46	November-December, '37	Southern California	37.64	2,747	1,713
38-1 to -9, -11	February-March, 1938	Southern California	36.76	5,675	3,589
38*-2 to -4, -8 to -11	February-March, 1938	Southern California	48.72	4,115	2,110
38*-18 to -20	May, 1938	Central California	24.97	793	595
38*-21 to -26	June, 1938	Southern California	55.03	3,162	1,422
39-1 to -9	February-March, 1939	Southern California	37.04	3,742	2,356
39-11, -12*, -13 to -18	September, 1939	Central California	31.45	3,472	2,380
39-25, -26	Dec., 1939	Southern California	28.35	1,379	988
40*-1 to -4	May, 1940	Central California	59.38	1,593	647
40-5, -8	August-September, 1940	Southern California	23.48	1,499	1,147
40*-6, -7, -9	August-September, 1940	Southern California	40.84	2,179	1,289
40*-10 to -24	October, 1940	Central California	52.72	9,164	4,333
40-25, -26	October, 1940	Central California	56.71	894	387
40*-31, -32	December, 1940	Southern California	50.32	2,033	1,010
41-2 to -8	January-March, 1941	Southern California	39.99	3,096	1,858
Totals			42.54	59,222	34,029

* Small tags were used on these groups and in general the fish were correspondingly small.

Measures of Abundance

After the tags are corrected by the above approximate values for tagging mortality and for efficiency of recovery, these corrected returns are affected by three remaining factors: fishing mortality, natural mortality and rapidity of dispersal of marked fish.

The measurement of fishing and natural mortality and the determination of the magnitude of the total population is the purpose of these studies on sardine tag returns. We are still faced, however, with the problem of dispersal of tagged fish throughout the entire population. That this is not rapid has been demonstrated by the data discussed in the section on movements of the population. Dispersal and its effect on measures of fishing and tagging mortality are discussed in the section dealing with rate of exploitation.

Methods of analysing returns from marked individuals in a population have been presented by several writers. Thompson and Herrington (1930), Thompson and Bell (1934), Graham (1938), and Jackson (1939) measured the rate of decline of tags returned in succeeding time intervals. This rate is influenced by tagging mortality, tag loss by shedding, failure to recover tags, speed of dispersal, fishing mortality and natural mortality. Thompson and Herrington and Graham discussed the inaccuracies arising from the influence of tagging mortality, tag loss and failure to recover tags but did not find it necessary to make corrections in their tagging experiments. For sardines, tagging mortality is high and adjustments are required. With a satisfactory correction for these three factors, the rate of decline will measure the summation of the effect of fishing and natural mortality from time interval to time interval provided marked fish are rapidly dispersed. Thompson and Herrington measured this rate by fitting a straight line to the logarithms of the tags recovered in each succeeding year expressed as the percentage of tags

unaccounted for at the beginning of each year. Graham fitted the line to the logarithm of the logarithm of the number of tags recovered in three-month intervals. The method used by Jackson has been tried but not found applicable to the sardine tag returns. All methods, however, determine the value of the intercept, at time 0, of the straight line fitted to the seasons' recoveries or factors of them. This value gives the number or percentage of tags that would have been returned were no factor operating other than fishing mortality. Because the magnitude of the intercept is affected by the number or percentage of returns at each succeeding time interval it represents the average fishing mortality over the entire series of intervals used in its calculation.

The time interval chosen for the sardine studies is the entire season, June 1st to the following May 31st. Tag returns were too few in number to justify the use of shorter time units. Two calculations have been made:

1. The fishing mortality and total decline based on tag returns from the catch off British Columbia, Washington, Oregon and California.
2. The fishing mortality and total decline based on tag returns from the California catch only.

The recoveries during the season in which the fish were tagged have not been included in the calculations. Tagging was carried on at various times within the season. As a result each tagging group was not submitted to an entire year of fishing during the first season and no satisfactory correction for this could be made. Their use, therefore, as a measure of fishing mortality or of rate of decline would not have given reliable results. The tags recovered during the season of tagging were deducted from the number of effective tags in each tagging group to give the number of available tags in the ocean at the beginning of the first season after tagging.

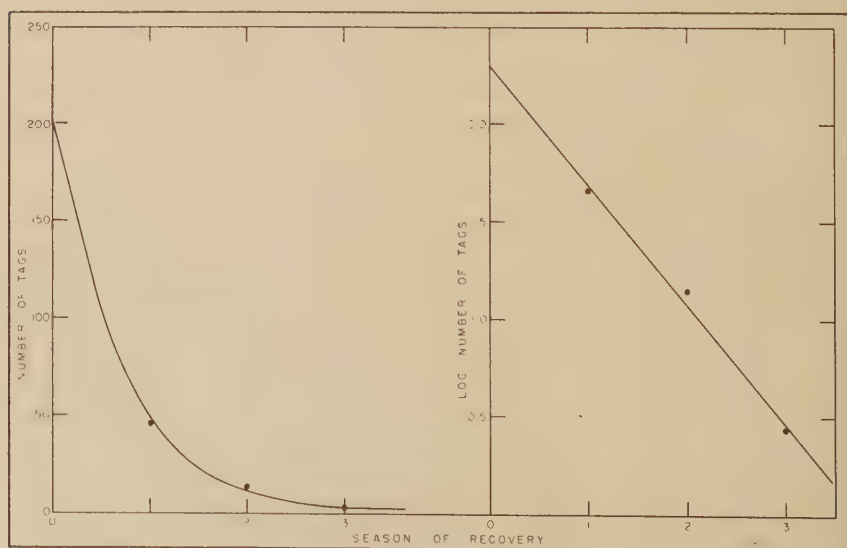


FIG. 5. Tags returned at 100 per cent recovery efficiency from tagging group 36-9, -10. The curve on the left shows the recoveries in natural numbers and on the right in logarithms. The straight line was fitted to the logarithms by the least squares method.

Jackson in his studies corrected the number of marked animals recovered in each succeeding time interval by the number of individuals marked in a group and by the total number of animals caught. This method would eliminate the effect of variations in the number of fish tagged and of variations in the number of all fish caught in succeeding seasons. More tags will be recovered from a large tagging lot than from a small and more tags will be recovered when a heavy tonnage is taken in a season than when the total catch is small. The desirability of eliminating the second influence is questionable. Such corrections were tried with the sardine tags but they gave results which did not differ from those for the uncorrected tags and their use was omitted in the final studies.

The method adopted was to fit a straight line to the logarithms of the numbers of tags recovered in each succeeding season; without correction for the number of fish in the total catch or for the number of fish originally released in a tagging group. The method may be illustrated by considering tagging group 36-9, -10 (Fig. 5). From this group 91 tags were recovered in the season of tagging and there were 633 effective tags released (Table 13). Deducting the tags recovered during the season of tagging leaves 542 tags available at the beginning of season one. In the three succeeding seasons 45.91, 14.04 and 2.77 tags were recovered (Table 15). To the logarithms of these numbers a straight line was fitted by least squares and the value of the intercept and the regression coefficient or slope determined. The antilogarithm of the intercept gives 201.0 tags recovered at time 0, or the beginning of season 1. There were

542 tags available and $\frac{201.0 \times 100}{542} = 37$ per cent¹. This value repre-

sents the theoretical fishing mortality if there had been no natural mortality. The slope of the straight line (expressed as a log value) is the equivalent of the logarithm of the average annual survival rate over the three seasons. The antilogarithm of this value is .2456 and the rate of decline becomes 75.44 per cent. This 75.44 per cent represents natural mortality plus fishing mortality, whereas, at time 0 only fishing mortality was operating. If the rate of decline or total mortality is represented by T, the fishing mortality by F and natural mortality by N, natural mortality may be calculated from the formula $F + N - \frac{FN}{100} = T$. For

this example the value of F is 37, T is 75 and N becomes 62 per cent. This represents the theoretical natural mortality had there been no fishing mortality. For this example the method of calculation gives unreasonable results but rate of dispersal has not been taken into account. Its effect is discussed under "Magnitude of the population".

Number of Fish in the Catch

Catch records for sardines are given in tons but all tag recoveries deal with individual fish. To use tag returns as a measure of population abundance we must translate the tons caught each season into numbers of fish. The sizes of sardines caught along the Pacific Coast of North America differ significantly between regions and a ton of fish

¹ It is not possible to make a correction for the loss of tags due to natural mortality between the time of release and the beginning of season one. As a result all estimates of fishing mortality are slightly less than the true value.

taken off British Columbia will not comprise as many fish as will a ton taken off southern California. From extensive weight-length data (Clark, 1928), conversion factors for different localities have been compiled and in table 14 are given the number of sardines caught in each region for the eight seasons involved in this study. We are indebted to Dr. J. H. Hart of the Pacific Biological Station at Nanaimo, B. C. for the conversion factors applied to the catch off British Columbia, Washington and Oregon.

Magnitude of the Population and Rate of Exploitation

Twenty tagging groups have been used in this study of the sardine population. In table 13 are given the date and locality of release for these groups, the number of fish tagged and the number of effective tags. Tags from these groups have been recovered from the fisheries off California, Oregon, Washington and British Columbia. In table 15 are shown, for the seasons 1936-37 through 1943-44, the actual number of tags recovered along the entire coast from each group and the number that would have been recovered had recovery methods worked at 100 per cent efficiency. In tables 16-20 the same data are assembled for recoveries from all the California fisheries and for each fishing region.

Using the method outlined above the theoretical number of tags to be expected at time 0 and the survival rate for each tagging group were calculated by fitting a straight line to the logarithms of the numbers of tags which would have been recovered at 100 per cent recovery efficiency. These values are given in table 21 for each of the twenty tagging groups. Since no adjustments were made for the different numbers of fish tagged, the theoretical numbers of tags to be recovered at time 0 are not directly comparable between groups; the survival rates are, however. The average survival rate is 39 per cent for the entire coast and 32 per cent for California only. The higher survival rate for the entire coast occurs among nearly all the tagging groups.

The average intercepts of table 21 are 532.3 and 650.7. These represent the theoretical tags to be expected at zero time for the entire coast and for California only. For the twenty tagging groups, the number of effective tags released was 34,029 (Table 13). Of these tags 1673 were taken in season 0. This number weighted to 100 per cent recovery efficiency is 3,568. Subtracting 3,568 leaves 30,461 effective tags at the beginning of season 1 which corresponds to time 0. The average number of effective tags is 1,523. The average fishing mortality independent

of natural mortality, becomes therefore, $\frac{532.3 \times 100}{1523}$ or 35 per cent

for the entire coast and $\frac{650.7 \times 100}{1523}$ or 43 per cent for California only.

It is evident that neither tag returns along the entire coast nor from California only yield reliable measures of survival rate, rate of decline or fishing mortality. If the California fishery drew from a different population than did the Pacific northwest, there need be no relationship between the rates of decline and fishing mortality for such independent populations. But if there is an interchange of fish between these two major fishing grounds, the rates should not be consistently higher when measured by California tag recoveries only. The results of the tagging experiments indicate that an exchange of sardines does occur between the fishing grounds.

TABLE 14

Number of sardines caught in each region for the seasons 1936-37 to 1943-44

Region	Season							
	1936-37	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44
British Columbia	238,000,000	201,300,000	203,500,000	21,900,000	138,500,000	406,000,000	365,000,000	425,000,000
Washington	35,100,000	72,000,000	104,100,000	74,000,000	4,000,000	151,500,000	13,600,000	63,300,000
Oregon	76,000,000	69,800,000	66,800,000	92,500,000	15,700,000	147,200,000		
San Francisco								
Shore plants	828,000,000	794,000,000	1,421,800,000	1,548,600,000	888,200,000	1,439,900,000	729,600,000	716,800,000
Floating plants	1,399,200,000	405,700,000	311,400,000					
Monterey	1,270,300,000	721,300,000	1,518,100,000	1,720,600,000	1,420,300,000	2,362,100,000	1,332,400,000	1,493,000,000
San Pedro	878,600,000	874,600,000	1,390,500,000	860,800,000	1,727,800,000	1,517,800,000	1,876,300,000	1,242,700,000
San Diego	29,100,000	900,000	26,700,000	900,000	11,900,000	16,000,000	26,500,000	25,300,000
Totals	4,754,300,000	3,139,600,000	5,042,900,000	4,319,300,000	4,206,400,000	6,040,500,000	4,343,400,000	3,966,100,000
Totals, California only	4,405,200,000	2,796,500,000	4,668,500,000	4,130,900,000	4,048,200,000	5,335,800,000	3,964,800,000	3,477,800,000

EIGHT SEASON AVERAGE

Region	Number		Tons		Region		Number		Tons	
Entire coast	4,476,600,000		605,600		Pacific Northwest		373,100,000		72,300	
California only	4,103,500,000		533,300		Central California		2,790,200,000		376,300	
					Southern California		1,313,300,000		157,000	

TABLE 16

Actual number and number at 100 per cent recovery efficiency of tags returned by seasons along the California coast from the tagging groups used in the study of the sardine population

Group	Number of tags recovered											
	1936-37		1937-38		1938-39		1939-40		1940-41		1941-42	
	Actual	@100%	Actual	@100%	Actual	@100%	Actual	@100%	Actual	@100%	Actual	@100%
36-1, -2	56	165.05	28	62.92	2	3.84	1	2.77	1	1.76		
36-9, -10	31	91.17	21	45.91	7	12.21						
37-7, -10 to -15, -19,												
-21 to -24	150	436.32	167	380.12	53	95.11	5	11.34	3	5.02		
37-26, -27			29	64.80	25	45.54	5	10.28	1	1.76		
37-30, -32, -34 to -36			222	501.88	37	68.44	7	13.15	1	1.52		
37-42 to -46			50	110.16	57	105.63	13	28.47	3	4.78		
38-1 to -9, -11			262	576.69	225	425.00	67	141.65	6	9.58	2	2.63
38-2 to -4, -8 to -11			46	115.96	151	353.58	54	131.41	17	31.44	3	4.66
38*-18 to -20					57	131.03	19	41.94	2	3.74		
38*-21 to -26					54	115.76	86	202.03	24	44.51	12	17.31
39-1 to -9					50	107.09	127	270.73	27	43.81	8	11.75
39-11, -12*, -13 to -18							345	665.42	57	99.01	5	6.73
39-26, -26							28	77.61	42	70.66	16	20.67
40*-1 to -4									45	81.23	19	25.20
40-5, -8									31	54.73	82	114.44
40-6, -7, -9									46	63.45	27	39.07
40*-10 to -24									54	84.20	23	31.32
40-25, -26									679	917.68	24	35.28
40-31, -32									235	397.44	212	305.86
41-2 to -8									24	36.75	7	8.98
									15	28.95	105	161.54
									16	28.10	180	243.78
											85	113.31
											38	50.01

* Small tags were used in these groups.

TABLE 21

Number of theoretical recoveries in 0 season, survival rate, and rate of decline for tags recovered from March 1935 through March 1941 and recovered from 1936-37 through 1943-44

Group	Recovered along entire coast			Recovered along California only		
	Theoretical recoveries	Survival rate	Rate of decline	Theoretical recoveries	Survival rate	Rate of decline
36-1, -2	434.6	.3450	.6550	492.1	.2665	.7335
36-9, -10	201.0	.2456	.7544	191.9	.2456	.7544
37-7, -10 to -15, -19, -21 to -24	1,670.0	.2649	.7351	1,654.0	.2908	.7792
37-26, -27	92.6	.3592	.6408	87.0	.3639	.6361
37-30, -32, -34 to -36	212.8	.3681	.6319	499.8	.1490	.8510
37-42 to -46	131.4	.4656	.5344	198.3	.3552	.6448
38-1 to -9, -11	1,215.5	.3142	.6858	1,562.0	.2271	.7729
38*-2 to 4, -8 to -11	1,114.5	.3337	.6663	1,072.0	.3254	.6746
38*-18 to -20	433.4	.2905	.7095	959.4	.1690	.8310
38*-21 to -26	323.9	.4636	.5364	324.3	.4574	.5426
39-1 to -9	600.9	.3520	.6480	543.0	.3162	.6838
39-11, -12*, -13 to -18	251.9	.3652	.6348	2327	.7673	.2327
39-25, -26	189.3	.3838	.6162	212.1	.3388	.6612
40*-1 to -4	307.2	.3686	.6314	456.9	.2705	.7295
40-5, -8	131.5	.4952	.5048	622.6	.2888	.7112
40*-6, -7, -9	176.3	.4623	.5377	219.0	.3928	.6072
40*-10 to -24	2,400.0	.3730	.6270	2,637.0	.3453	.6547
40-25, -26	28.9	.4766	.5234	28.9	.4766	.5234
40*-31, -32	275.1	.6067	.3933	301.0	.4330	.5670
41-2 to -8	455.6	.5165	.4835	542.5	.4531	.5469
Totals	10,646.4	7.8533	12.1467	13014.1	6.4617	13.5383
Average	532.3	.3927	.6073	650.7	.3231	.6789

* Small tags were used in these groups.

An explanation for a higher rate of decline when measured from California recoveries is that the total decline thus calculated includes not only natural and fishing mortality but also a loss due to an emigration away from the tagging area. It is not known how much recoveries along the entire coast compensate for this emigration loss. This partial compensation is also involved in the tag returns from California only. A group of tags released in southern California will not completely disperse to all fishing grounds in one season, nor will groups released in central California. The problem is further complicated by the fact that the larger fish move away from the tagging area more rapidly than do the smaller sardines. At present there thus appears to be no method by which a rate of decline may be obtained that will be free from the effects of emigration from the region of release and immigration to other fishing grounds.

Tag returns from the region of release over succeeding seasons are affected, however, principally by emigration.² It is thus possible to use the recoveries in southern California from releases in the same area to measure a rate decline over succeeding seasons. This rate is the sum of natural and fishing mortality and loss due to emigration. Recoveries in central California from central California releases can be similarly treated. Unfortunately for any given tagging group the number of recoveries in the region of release during the following seasons is not large. To obtain reliable numbers it is necessary to combine recoveries from all groups. This was done by summing recoveries in season one, season two, etc. Since groups 40-1 to 41-8 have been exposed to the fishery for three seasons only, the combination was made on the first three seasons for all groups. Recoveries in southern California from southern California releases were combined and central California tagging groups were treated in a similar manner. The number of tags involved are given in table 22. Central California groups include releases and recoveries at San Francisco and Monterey.

TABLE 22

Sardine tag recoveries in the region where released for southern and central California tagging groups

Season of recovery	Central California groups		Southern California groups	
	Actual	@100%	Actual	@100%
-----	780	1,080.27	445	880.54
-----	204	287.45	132	237.63
-----	72	110.39	36	55.48

A straight line fitted to the logarithms of the tags recovered in central California gives a rate of decline of 68.03 per cent and an expected tag recovery at time 0 of 3177. The same values for southern California recoveries are 74.90 per cent and 3595 tags. These rates of decline represent the sum of natural and fishing mortality plus the loss due to emi-

² Tagged fish which move away from the area of release and return in one season have the same effect on the tag returns as fish which remained in the area. Those which migrate out of the area but return in later seasons tend to decrease the losses due to emigration and to produce irregularities in the data. Such movements do not produce an increase in the measure of total decline.

gration. For the central California tagging groups there were 81 available tags at time 0 and $\frac{3177 \times 100}{8146}$ gives a potential fishing mortality of 39.0 per cent if there had been no loss due to natural causes and emigration. From the formula $F + N - \frac{NF}{100} = 68$, the value of N will be 47.54 per cent. In this formula F is the potential fishing mortality and N the sum of natural mortality and emigration were there no loss due to fishing. The amount that the central California fishermen took from the population concurrently with natural mortality and emigration can be calculated by the formula $\frac{F}{F + N} \times T$, where T is the total decline. This termed rate of exploitation by Ricker (1944). From the above figures $\frac{39}{39 + 47.54} \times 68$, the rate of exploitation for the central California fishery is 30.7 per cent.³ This represents the average annual rate for the seasons 1936-37 through 1943-44. During these eight seasons the central California fishery had an average catch of 2,790,200,000 fish (Table 14). From the ratio 31 per cent : 2,790,200,000 = 100 per cent : x, the total population will be 9,000,600,000 fish.

For the southern California returns the total decline is 74.90 per cent and the expected recovery at time 0, 3595 tags. At time 0 there were 22171 available tags and the potential fishing mortality is $\frac{3595 \times 100}{22171}$ or 16.2 per cent. From the formula, $16.2 + N - \frac{16.2N}{100} = 74.9$, N has a value of 70.0 per cent and from $\frac{FT}{F + N}$, the rate of exploitation for southern California is 14.1 per cent. The average annual southern California catch (Table 14) was 1,313,300,000 fish and the total population is calculated as 9,314,200,000 sardines.

If we accept the evidence, as indicated by tag returns, that all the fisheries along the Pacific Coast are drawing from the same sardine population, the returns from the central and southern California tagging groups constitute two independent measures of the magnitude of the population. The results are in close agreement. It would be desirable to make a similar calculation from tags released by Canada in the Pacific northwest but no tags have been recovered in the region where released after the second season following tagging and the data are inadequate. The figure of approximately 9 billion fish represents only sardines large enough to be taken by the commercial fishery. Young fish, sizes unsuitable for bait and smaller, are not included in the measure.

In fisheries administration it is advantageous to know the natural mortality independent of fishing mortality. From tag returns, however, this is not obtainable because the measure of total decline involves

³Using Ricker's formula (7) the rate of exploitation for central California is 29.7 per cent and the total population 9,363,000,000 fish. For southern California the values are 9.7 per cent and 13,483,000,000 fish. For a population of 11.5 billion fish the rate of exploitation along the entire coast is 39 per cent. A 50 per cent rate of exploitation as given by the approximate calculation seems more reasonable than a rate of 30.7 per cent. Because conditions in the population are complex, Ricker's formula may not be applicable to sardine tag returns. Until more accurate data are available the approximate method of calculation has been used.

three factors, fishing and natural mortality and loss due to emigration. If the above measures of the size of the total population are valid it is possible, none the less, to estimate rate of exploitation along the entire coast. The average annual catch for the eight seasons was 4,476,600,000 sardines (Table 14). If we consider the total population was 9 billion fish, the rate of exploitation is 50 per cent. If the total population is 9.5 billion the rate becomes 47 per cent. Of the total catch of 4476.6 million fish, the Pacific northwest fishery took 373 million, central California 2790 and southern California 1313, or 8.3, 62.3 and 29.3 per cent respectively. For the 50 per cent total exploitation rate, the rates from the three fisheries are therefore 4, 31 and 15 per cent.

The eight-season annual tonnage averaged 605,600 (Table 14) along the entire coast and of this tonnage 11.9 per cent was taken in the Pacific northwest, 62.0 per cent in central California and 25.9 per cent in southern California. On the basis of tonnage taken the exploitation rate of 50 per cent is composed of 6 per cent from the Pacific northwest, 31 per cent from central California and 13 per cent from southern California.

SUMMARY

Sardines tagged by an internal metal tag have been released on fishing grounds from British Columbia to Magdalena Bay, Lower California.

Fish tagged by the California Division of Fish and Game in Mexican waters have been retaken in the California fishery off San Diego, San Pedro, Monterey and San Francisco. Sardines tagged in central and southern California have been recovered in all the California fisheries and in the Pacific northwest. Fish marked in the Pacific northwest by the Canadian and Oregon governments have been recovered in the California fisheries.

The rapidity of movement of tagged fish varies with size. The largest sardines will migrate from southern California to British Columbia in five to six months and fish tagged off British Columbia have made the southern migration in the same time interval. Smaller fish do not move as rapidly and several years will elapse before an average-size lot of tagged sardines has spread to distant fishing grounds.

Recoveries from tagged sardines can be used to measure the average size of the sardine population but caution must be exercised in interpreting the results. Releases must be corrected for losses due to tagging mortality and to number of tags shed and recoveries must be adjusted for efficiency of recovery methods. Because of the effect of migration, tag returns can not be used to measure the fishing and natural mortality. By using recoveries in the region of release in succeeding years this effect of migration can be held to a minimum and the recoveries can be used as a basis for estimating total population.

After applying the most accurate corrections available for the above factors the average size of the sardine population between 1936 and 1944 was estimated at nine billion fish. This number represents fish large enough to be taken for canning and reduction purposes. From this population the fishery took approximately 50 per cent each season, 4 per cent in the Pacific northwest and 46 per cent in California.

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THE EFFECT OF INTERNAL TAGS UPON SARDINES

By JOHN F. JANSSEN, JR. and J. ALFRED APLIN

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INTRODUCTION

Sardines, *Sardinops caerulea* (Girard), were originally tagged along the Pacific coast of North America to learn more about their migrations. For this, a knowledge of the extent of mortality caused by tagging was relatively unimportant as long as satisfactory recoveries were obtained. But the recoveries far exceeded all expectations and it became evident that they might possibly be used in studies other than migration. With the aid of tag recoveries it is theoretically possible to calculate the proportion of the entire exploited population removed from the ocean over a period of time by fishing operations. To carry this one step farther, it is possible to approximate the size of the exploited population. However, several errors complicate the problem and two of the greatest are the death of fish incident to tagging and the shedding of tags.

If 10,000 fish are tagged and 500 of these tags are later recovered there has been a 5 per cent recovery. Suppose the landings during the period of recovery totaled 100,000,000 fish. If it can be assumed that the tagged fish were evenly distributed in the population, it is safe to say that there were 500 tagged fish in every 100,000,000 of the fish in question in the ocean. The total catch of 100,000,000 fish therefore represents $\frac{500}{10,000}$ or $\frac{1}{20}$ of the total exploited population. The entire exploited population will be $20 \times 100,000,000$ fish or 2,000,000,000 fish. If there was a relatively high tagging mortality, say 50 per cent, the recovery of tags becomes 10 per cent instead of 5 per cent and the size of the population becomes 1,000,000,000 fish or half as many as the original calculations. From this it is obvious that without a correction

for tag loss through shedding and death of sardines no valid conclusions may be drawn concerning the size of the exploited population.

The first objective of the following experiments was, therefore, to find the proper mortality correction to apply to each group of fish tagged. Involved in this problem of tagging mortality is the relative mortality of different sized fish. It is quite conceivable that very small fish will not survive the tagging operation as successfully as large fish so that different corrections will have to be applied depending upon the sizes of the fish in each tagging group.

A secondary objective of the experiments was to determine whether there are significant differences in the efficiency of large versus small tags, round-ended versus square-ended tags, and inserting tags by the scalpel-forcep method versus the tagging gun method. The efficiency of cadmium-plated tags was also tested.

The experiments were conducted by holding tagged sardines in a floating live box. An effort was made to put as many fish as possible into each experiment so as to overcome some of the disadvantages of small numbers. The limiting factors were the number of fish the floating live box compartments could accommodate and the number of fish available. For sardine tagging, internal belly tags of four different types have been used. (Fig. 3). They have been inserted by scalpel and forceps and by means of a tagging gun.

RESULTS OF THE EXPERIMENTS

The experiments were planned to test tagging mortality on small fish (under 18.5 cm. total length), medium sized fish (18.5-25.0 cm. total length) and large fish (over 25.0 cm. total length). However, due to difficulties in obtaining sardines in these various ranges the experiments comprised chiefly small fish with only a few of medium sizes and no large ones.

Although the results from supposedly comparable experiments showed great variation, the following general conclusions can be drawn: When small tags are applied to small fish there is on the average about 60 per cent mortality resulting from tagging. When either large or small tags are used in medium sized fish the average mortality is in the neighborhood of 40 per cent. Among large fish it is probably little, if any, lower.

Owing to excessive mortality, it is not advisable to tag sardines smaller than 14 cm. total length.

The small tag should be used for fish under 19 cm. total length. For fish over 19 cm. either tag is equally efficient as regards mortality due to tagging. However, the large tag is recommended for medium and large sized fish as it is the easiest to apply and is recovered most effectively by magnets. (See Measurement of the losses in recovery of sardine tags.)

There is no significant difference between the effectiveness of tags with rounded ends or with square ends.

There is less shedding among scalpel-forcep tagged fish than among gun tagged fish, but the proportion of deaths is about the same in either case.

An experienced tagging crew seems to do a more effective job of tagging than a less experienced crew.

Death from tagging occurs within the first ten days.

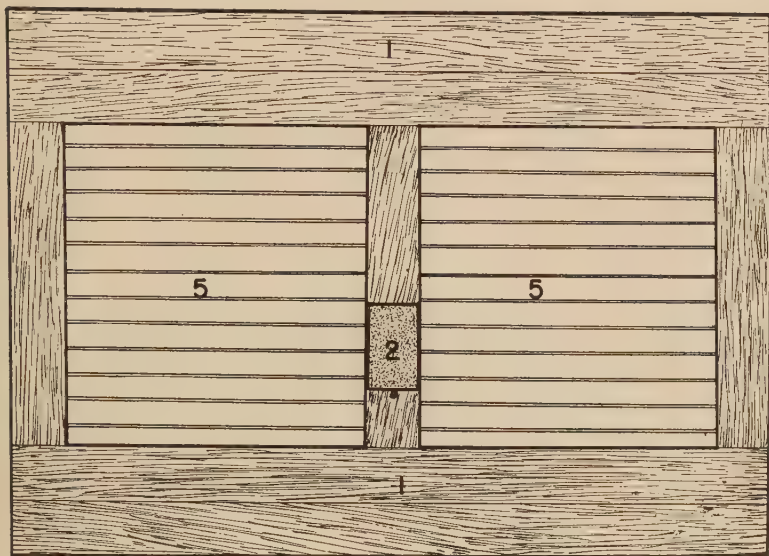
Shedding of tags appears to be negligible after two months.

Cadmium-plated tags cause 100 per cent mortality among sardines.

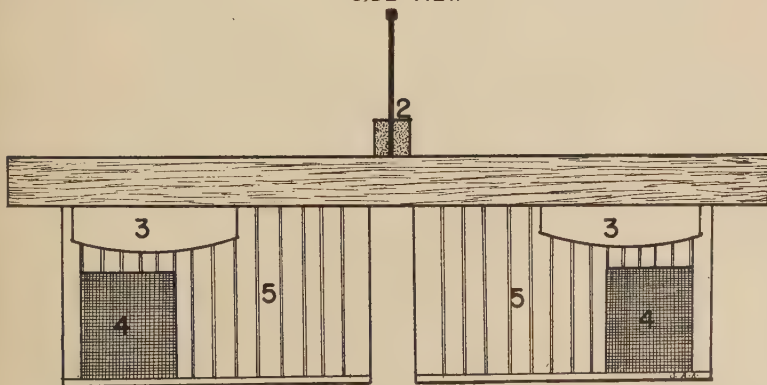
Internal tags usually become encysted in the body cavity of sardines.

With ample food and water circulation sardines have been held in a floating live box for five months and possibly could be held indefinitely.

TOP VIEW



SIDE VIEW



1. DECK

2. BATTERY BOX

3. EMPTY 50 GALLON DRUMS

4. WIRE WINDOWS

5. SLAT COMPARTMENTS

FIG. 1. Diagram of the floating live box.

THE FLOATING LIVE BOX

The live box or fish holder used in these experiments was similar to the "bait receivers" used by the live bait fishermen in southern California. The float was made of 2x12 planking notched together at the joints. Four empty 50-gallon oil drums were put under the float to give it buoyancy. The first unit was built with two removable fish compartments made of lath, but these proved too weak. Satisfactory compartments were made of vertical 1x4's with cracks of about $\frac{1}{2}$ inch between. These were fastened to a heavy frame of 2x4's and 4x4's bolted together. The compartments were six feet square and four feet deep. Covers, made of 1x4's spaced about six inches apart and with wire screen stretched over them, served to keep out predators as well as excessive sunlight. For the first experiments one end of the live box was moored to a jetty and the other end was anchored. This location, in the entrance channel to Newport Harbor, was occasionally subjected to a heavy surge during storms. As a result, the float broke its moorings twice so that a new location was found before the second series of experiments was started. At the second location, farther up the channel, the water was calm at all times. For these experiments another receiver was added, identical to the first. The receivers were then fastened between an anchor on the beach and a weight placed well out in the channel. This spot was more than two miles from the opening of the bay so the water temperature was often considerably higher than that of the open ocean. The marine growth was more abundant which made it necessary to clean the cracks in the sides every week to allow circulation of water within the compartments. It was also found to be advisable to construct in each compartment two "windows" each two feet square and covered with $\frac{1}{2}$ inch mesh hardware cloth.



FIG. 2. Fish tagging on the floating live box. Photo by D. H. Fry, Jr.

The commercial men have found that confined sardines will injure themselves against the sides of the container at night unless the compartments are lighted. A one-candlepower electric bulb in each compartment, suspended in the middle just below the surface of the water, was found adequate. The electricity for these lights was supplied by dry batteries at first and later by a storage battery. To conserve the electricity a thermostat was mounted on the battery box which kept the lights turned off when the sun shone.

TYPES OF TAGS USED

Sardine tags used by California investigators are of two sizes. The large tag is 19 mm. long by 4 mm. wide by 0.6 mm. thick ($\frac{3}{4} \times \frac{5}{8} \times \frac{1}{40}$ inch). The small tag is 12.7 mm. long by 3.2 mm. wide by 0.6 mm. thick ($\frac{1}{2} \times \frac{1}{8} \times \frac{1}{40}$ inch). Some of each size have rounded ends, others have nearly square-cut ends. Separate records were kept for each type of tag.

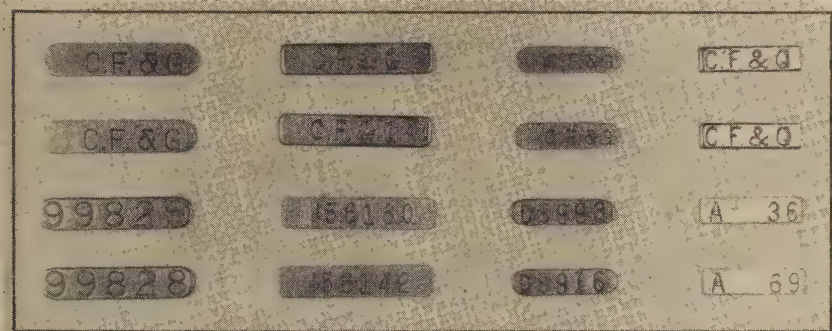


FIG. 3. Examples of tags used by California workers in the study of sardine migrations.

METHODS OF TAGGING SARDINES

The scalpel-forcep method of tagging has been used exclusively by California investigators to tag sardines released in the ocean (Janssen 1937, 1938). Most of the fish in the holding experiments were tagged in this manner. In British Columbia some sardines as well as herring have been tagged by a scalpel method. There the fish are not measured and the entire operation is performed by one man (Hart, 1937.1, 1937.2, Hart and Tester, 1937.1).

The sardines tagged by Oregon authorities have all been tagged with a tagging gun, as have some in British Columbia. The gun method is performed by a single man and the fish are not measured. In our three holding tank experiments in which the tagging gun was used an attempt was made to follow closely the technique used by the northern workers (Hart, 1938, Hart and Tester, 1938).

METHODS OF OBTAINING THE SARDINES

Small Fish

All of the small fish (under 18.5 cm. total length) were obtained from a commercial live bait fisherman working out of Newport Harbor. The several groups of fish thus secured were caught early in the morning near Newport in an 85-fathom lampara net operated from a 36-foot boat. The fish were carefully dipped from the net into a live bait tank through which ocean water was constantly circulating. The boat carried the fish to the floating live box and enough for one experiment were placed in one compartment.

The fish were confined on one side of the compartment with a curtain of webbing so they could be dipped one at a time for tagging by the scalpel-forcep method. As they were tagged they were placed in an adjoining compartment. After 10 to 25 fish had been tagged an equal number was dipped across the curtain of webbing to be held as controls in the same compartment. The procedure was continued until all of the fish confined by the webbing were in either the tagged fish or control compartment.

Medium Sized Fish

During the two seasons in which the experiments were conducted, medium or large sardines failed to appear in the vicinity of the floating live box. It was necessary, therefore, to use a speed boat and bring the fish some 30 nautical miles to the live box from the nearest locality in which they were available. The fish, caught at night by a commercial sardine purse seiner, were dipped from the net and placed in a well-lighted tank of circulating water. When the boat arrived alongside the floating live box the fish were tagged directly from the tank. One crew inserted tags by the usual scalpel-forcep method. Another man tagged with a tagging gun. These fish were placed together in one compartment and the controls were put into another.

CARE OF THE SARDINES

The floating live box was visited each day for a week or two after a new experiment had been started. Thereafter it was visited every second or third day. The fish were fed at each visit and all dead fish removed. Dead tagged fish were measured and their body cavities opened to determine the position of the tags, the tag numbers, and whether the tags were encysting. Frequently a magnet suspended from a string was dragged over the bottom of the compartment to pick up shed tags. A few shed tags went through the bottom of the live box but they were included at the end of the experiments as the number of unaccounted for tags. After mortality ceased, the controls were tagged for another experiment. These controls when tagged are termed conditioned fish. When the experiments were concluded, all of the remaining fish were autopsied to determine whether they still bore tags, the position of the tags in the body cavity and the degree of encystment.

Because the sardines could not obtain enough plankton to sustain them over a long period of confinement, feeding was necessary. Fresh fish were ground very finely and stirred thoroughly into a bucket of water. This forced most of the small particles into suspension. The

liquid was then poured a little at a time into the fish compartments. Sardines were used when they were available but practically any kind of fish was found to be suitable.

Corn meal was tried as an addition to the ground fish diet. The fish would eat it as they would any small particles in the water, but they did not seem to thrive upon it. A very satisfactory supplement to ground fresh fish was a commercial stock food consisting of a mixture of finely ground kelp and fish meal. This mixture was sprinkled liberally over the surface of the water. As it was very dry it tended to float and the particles fell gradually as they became wet. This seemed to approach normal plankton feeding as nearly as could be conveniently attained in confinement.

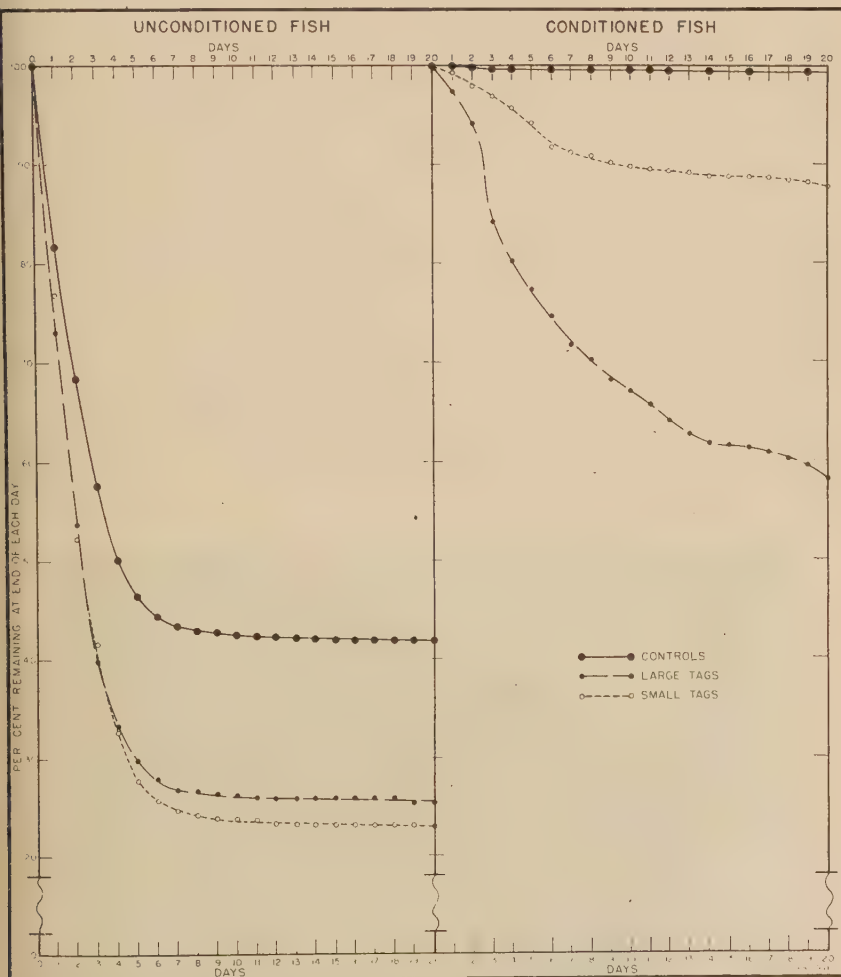


FIG. 4. A mortality curve showing the average percentage of the fish remaining alive at the end of each day. All experiments with large tags averaged, all experiments with small tags averaged, and all controls averaged. Cadmium plated tags and tags applied with the tagging gun are excluded. After 20 days there were few deaths.

BEHAVIOR OF SARDINES IN THE LIVE BOX

For several hours after being placed in their new environment the sardines wander in all directions. Gradually the entire group commences to mill or circle as a unit either in a clockwise or counter-clockwise direction. After the milling has started it never stops unless the fish are seriously disturbed, after which it commences anew.

Many of the fish lose scales to a greater or lesser extent incident to catching, transferring into the live box, and handling while being tagged. Loss of scales combined with other injuries results in deaths within a very few hours after the fish have been placed in the live box. These deaths continue for about six days after which few fish die (Fig. 4).

By the third or fourth day the fins and tails are noticeably frayed and worn off at the ends. This condition becomes worse for several days and then the fins commence to heal. Complete repair is slow and in some instances was not complete in the five months of the longest experiments. About the third or fourth day infections develop on the fish. These points of infection may occur anywhere on the surface of the sardine and be of almost any size although they are usually quite small. The infections appear to develop where slime or scales or both have been rubbed off. If the fish does not die the injuries heal within a period of two weeks. Such infections never reappear after they have once healed even among conditioned fish which are tagged. New scales form where they have been lost and within a month there is no evidence of scale loss nor a scar where the tag was inserted.

After a few days of confinement the fish respond very actively to food. The presence of small particles in the water stimulates the feeding activity. The kind of particles seems to be immaterial. Iron filings or sawdust produce the same effect as corn meal, ground fish, or fish and kelp meal. While feeding, the sardines swim rapidly with their mouths partly open and their opercles well apart to allow a substantial circulation over their gill rakers.



FIG. 5. Sardines being fed in the live box.

The longest time that sardines were held in any of the experiments was approximately five months. At the end of this time the fish were very fat and apparently in excellent condition. With ample food and water circulation it is believed they could be held indefinitely.

DETERMINATION OF TAGGING MORTALITY

Methods

In order to estimate tagging mortality it is necessary to know the number of tag-bearing fish that survive in each experiment. Fish which have shed their tags may be considered dead for all practical purposes.

When conditioned fish were tagged without controls the mortality resulting from tagging was calculated for each experiment by totaling the number of fish which died and the number which shed tags, and then dividing this figure by the number of fish originally tagged. These figures expressed in percentage are shown in table 1, and involve experiments 1938-2 and 1939-3, -6, -7. As the mortality among untagged conditioned fish proved slight it was deemed unnecessary to keep controls with tagged conditioned fish to make a correction for deaths caused by confinement.

When unconditioned fish were tagged controls were always held. For each of these experiments the following percentages were calculated and are given in table 1: The percentage of fish which lived to the end of the experiment and still bore tags, column 3. The percentage that shed tags, column 4. The percentage that died bearing tags, column 5. The percentage of controls that lived to the end of the experiment, column 8. The percentage of controls that died during the experiment, column 9. For the tagged fish, the total loss as the result of tagging is the sum of those which shed tags and those which died bearing tags. This value given in percentage in column 6 can be obtained by summing the numbers in the two categories and dividing by the total number tagged or by summing the percentages of columns 4 and 5.

The percentage values of column 6 represent the total tagging mortality resulting from the shedding of tags and from all other causes, such as catching the fish, dipping them from the net into the bait tank on the boat, transporting the fish and placing them in the live box, tagging the fish and holding them in the live box. The percentage of loss among the controls, column 9, results from catching, dipping into the bait tank on the boat, transporting to and placing in the live box, and from holding in the live box. If this loss resulting from handling and holding the fish is deducted from the total loss from all causes, the remaining loss represents the tagging mortality resulting from placing tags in sardines and from shed tags. This represents a minimum tagging mortality which would be attained under more ideal conditions than are realized in ordinary tagging practice. It has proved a useful measure, however, and its application to tag returns is discussed in "Movements and abundance of the sardine as measured by tag returns."

Since the data of table 1 are percentage figures and the factors producing the values from which they were derived are interrelated processes, the combination of the percentages into a minimum tagging mor-

tality, column 10, is complex. If the loss of tagged fish is great, few tags will be shed because fish will die before they have time to shed tags. (Death occurs within one to two weeks while shedding may continue for a couple of months.) Conversely, if a few fish die from the combined effect of the tagging process more tags will be shed. Since we are only interested, however, in the number of fish which lived and retained tags it is not necessary to calculate the number which would have shed tags if no deaths had occurred nor the number of fish which would have died bearing tags had no tags been shed. The sum of these losses, termed L, is represented by the percentages given in column 6.

In each experiment a certain percentage die bearing tags. These deaths represent loss resulting from the many processes to which the fish are subjected. Among the controls a percentage loss also occurs resulting from all the processes which the fish undergo except the insertion of tags. If L represents the percentage which die bearing tags plus the percentage which shed tags and c the percentage loss among the controls, column 9, we can calculate the loss resulting from tag insertions, or minimum mortality, termed m, from the formula $m + c - \frac{m \cdot c}{100} = L$. Using the data for 1938-1, we have $m + 44.0 - .440m = 76.8$ and m becomes 58.6 per cent.¹

The minimum mortality values of table 1 were calculated in this way. Obviously, the tagging mortality determined in any experiment is the most conservative estimate obtainable under conditions relative to that particular experiment. As conditions are seldom, if ever, identical for any two groups of tagged fish, the several holding experiments were performed to arrive at an average minimum mortality.

No correlation was found between mortality and numbers of fish confined in the live box. This was true for both controls and for tagged fish. Furthermore, commercial live bait dealers frequently hold live sardines for weeks under more crowded conditions than were imposed upon any fish in these experiments. It may be assumed therefore that the fish were never crowded to the point where their numbers caused more deaths than would have resulted if they had been less crowded.

There is a possibility that infection is spread among the fish due to confinement. When there are controls this factor is compensated among the tagged fish by taking into consideration the mortality among the controls.

Mortality Among Small Fish

In all experiments where small tags were used in groups of predominately small fish the average minimum mortality caused by tagging was 53.8 per cent (Table 2). On the other hand, the average minimum mortality resulting from inserting large tags into groups of predominantly small fish was 64.2 per cent. For fish under 16 or 17 cm. total length it is evident that small tags are more efficient than large tags.

¹ These calculations are the equivalent to $100 \frac{s + d - c}{e} =$ The maximum number of survivals out of each 100 tagged, when s represents the number of fish which would have shed tags had no deaths occurred, d the number which would have died bearing tags had no tags been shed and c the loss among the controls.

Experiment number	TAGGED FISH					CONTROL FISH			
	2	3	4	5	6	7	8	9	10
	Number of tagged fish	Percentage that lived to end of experiment bearing tags	Percentage that shed tags	Percentage that died bearing tags	Total tag loss in percentage (4+5)	Number of controls	Percentage that lived to end of experiment	Percentage that died	Minimum tagging mortality in percentage m
1938-1	108	23.2	4.6	72.2	Plated Tags Scalpel-Force ep Method	498	56.0	44.0	58.6
1938-3*	248	45.2	14.1	40.7	76.8	629	99.2	0.8	54.4
1939-1	148	31.0	3.4	65.6	69.0	304	47.4	52.6	34.6
1939-2	131	6.1	2.3	91.6	93.9	305	7.9	92.1	22.8
1939-3*	90	93.3	3.3	3.4	6.7				6.7
1939-4*	98	42.8	8.2	49.0	57.2				57.2
1939-7*	150	13.3	31.3	55.4	86.7				86.7
1939-1	142	14.1	15.5	70.4	Large Nickel Tagging Gun Method	304	47.4	52.6	70.3
1939-2	153	2.0	3.9	94.1	85.9	305	7.9	92.1	74.7
1939-3*	75	68.0	25.3	6.7	32.0				32.0
1938-1	297	24.9	6.1	69.0	Plated Tags Scalpel-Force ep Method	498	56.0	44.0	55.5
1938-2*	268	72.0	17.9	10.1	75.1				28.0
1938-3*	464	76.3	11.2	12.5	28.0	629	99.2	0.8	23.1
1939-4	395	6.3	1.8	91.9	23.7	945	37.1	62.9	83.0
1939-5	592	22.1	4.7	73.2	93.7	639	60.3	39.7	63.4
1939-6*	74	50.0	20.3	29.7	77.9				50.0
1939-7*	146	26.7	58.2	15.1	50.0				73.3
1939-6*	97	0.0	0.0	100.0	Large Cadmium Plated Tags Scalpel-Force ep Method				100.0
1939-7*	97	0.0	3.1	96.9	100.0				100.0

* Conditioned fish.

Mortality Among Medium Sized Fish

When large tags were used in groups of predominately medium sized fish the average minimum mortality due to tagging was only 20.6 per cent (Table 2). This figure was based upon only two experiments (1939-1 and -3) so that it may not be very reliable. Experiment 1939-2 belongs to this category but was not included in the calculations. For some unexplained reason practically all of the controls (92.1%) as well as tagged fish in this experiment died. Since there were only three experiments involving medium sized fish the inclusion of experiment 1939-2 would have unduly influenced the average.

TABLE 2

Mortality resulting from tagging

Experiment number	MINIMUM MORTALITY			MAXIMUM MORTALITY		
	Small sized fish		Medium sized fish	Small sized fish		Medium sized fish
	Large tags, per cent	Small tags, per cent	Large tags, per cent	Large tags, per cent	Small tags, per cent	Large tags, per cent
1938-1	58.6	55.5		76.8	75.1	
1938-2*		28.0				
1938-3*	54.4	23.1				
1939-1			34.6			69.0
1939-3*			6.7			
1939-4		83.0			93.7	
1939-5		63.4			77.9	
1939-6*	57.2	50.0				
1939-7*	86.7	73.3				
Average mortality	64.2	53.8	20.6	76.8	82.2	69.0

* Conditioned fish.

Fish tagged by means of the tagging gun or with cadmium plated tags are excluded. Experiment 1939-2 is excluded as noted in the text.

The results indicate that large tags are more efficient for medium sized fish than for small fish. This is further suggested in figure 6 which shows frequencies of fish that died and shed tags compared with frequencies of fish that lived. All experiments with large tags were combined as were all experiments with small tags. No small tags were put into groups of predominately medium sized fish. However, in the few fish of 17 cm. total length or over that were tagged with small tags the mortality seemed to be about the same as for large tags.

Conclusions

The experiments were not extensive enough to permit the assignment of a definite average mortality resulting from tagging to a group of fish. Maximum and minimum mortality define the range within which the mortality resulting from tagging is most likely to fall. Table 2 shows the maximum and minimum mortality percentages for small and for medium sized fish. Mortality caused by tagging as used in this section includes fish that shed their tags as well as those that died.

Minimum mortality was calculated from experiments which included controls and from experiments on conditioned fish. In the experiments using controls, the mortality resulting from all factors

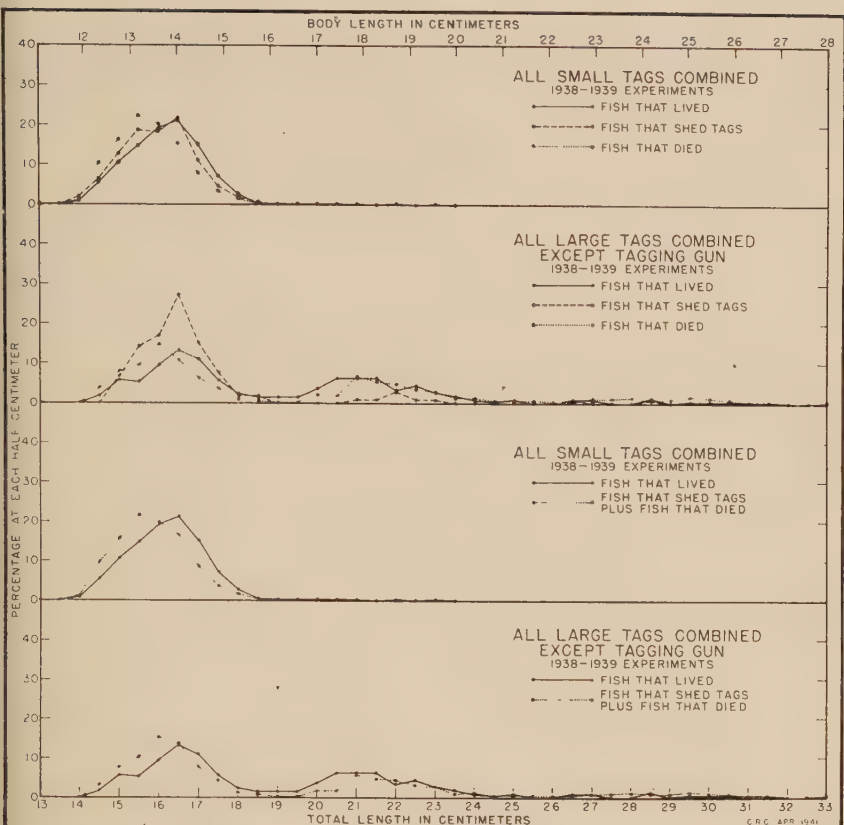


Fig. 6. Length frequencies of fish which died and shed their tags compared with fish which lived. All fish tagged with small tags combined and all those tagged with large tags combined. Fish tagged with cadmium plated tags or with the tagging gun excluded.

except insertion of tags has been deducted from the mortality of the tagged fish so that the remaining mortality figure corresponds to that of conditioned fish. This minimum mortality resulting from tagging may therefore be considered a measure of mortality under the most favorable tagging conditions—conditions which are scarcely ever attained in normal tagging procedure. The average minimum mortality for small fish tagged with large tags is 64.2 per cent and for small fish tagged with small tags is 53.8 per cent. For medium sized fish the average minimum mortality is 20.6 per cent with large tags. No tests were made with small tags.

The maximum mortality is calculated from fish which were tagged immediately after capture (unconditioned fish) and measures the mortality resulting from catching the fish, transporting them to the floating live box, applying the tag and keeping them in confinement for the duration of the experiment.

For small fish tagged with large tags only one experiment is available. It gives a maximum mortality of 76.8 per cent. The three experiments on small fish tagged with small tags give an average maximum

mortality of 82.2 per cent. This difference between large and small tags is not considered significant because of the few experiments involved. The maximum mortality of small fish probably lies between 75 and 80 per cent. For medium sized fish the one experiment shows a maximum mortality of 69.0 per cent for large tags. No small tags were put into groups of predominately medium-sized fish.

Figure 7 shows the average mortality at each half centimeter of length for fish that died or shed their tags.² All experiments were combined and represent a combination of fish tagged under favorable as well as unfavorable conditions. The mortality of the controls was not deducted. This figure shows more clearly than does table 2 the effect of tagging upon different sized fish. Among sardines less than 19 cm. total length, the mortality from the insertion of large tags is greater than for small tags. For fish about 14 cm. total length the mortality lies between 70 and 80 per cent, and decreases consistently until it levels off at about 40 per cent at sizes of 18 to 19 cm. This level is maintained until sizes of approximately 21 cm. are reached. From 21 to 24 cm. the mortality of medium sized fish is around 50 per cent. This slight increase occurs because of the smaller number of medium sized sardines and because of fewer experiments involved. Had the number of experiments been adequate it seems probable that the mortality for medium sized fish would have been around 40 per cent. No information is available for fish larger than 24 cm. as their number were too few to be significant.

Although positive conclusions cannot be drawn from these data, the following statements seem justified. Small fish, i.e., 18 cm. total length or less, if tagged with small tags, will suffer a minimum mortality of about 50 per cent, a maximum of about 80 per cent, and an average of about 60 per cent. Medium sized fish, i.e., from 18 to 24 cm. total length, if tagged with large tags experience a minimum mortality of about 20 per cent, a maximum of 70 per cent and an average of about 40 per cent.

ROUND-ENDED VERSUS SQUARE-ENDED TAGS

There are only three experiments in which a direct comparison may be made between tags with square ends and tags with rounded ends (Table 3). Although the shedding was 0.9 per cent less and the deaths were 1.1 per cent less among the fish tagged with square-ended tags, the differences are not significant. To each of the three comparable experiments a chi-square test was applied. The resulting chi-squares were added as were the degrees of freedom to obtain a measure of the significance of the difference between the averages in table 3 (Yule and Ken-

²In order to give each experiment equal weight the percentage of fish which died and shed tags at each half centimeter of length was determined for each experiment. These percentages were averaged and plotted as shown in figure 7. The numbers of fish in the various experiments were quite variable (Table 1) as was the relative condition of the fish in the different experiments. An exceptionally numerous group of fish in unusually good or poor condition would unduly influence the average on a direct numerical basis. Assuming the number of fish within each experiment to be adequate, the average percentage of fish which died and shed at each unit length gives an estimate of average mortality under average conditions. To further test the validity of this method of treatment, a chi-square test was applied to the experiments concerned to determine the probability that the fish composing the different experiments were of the same relative condition at the start of the experiments (Snedecor, 1938, p. 171). There is more than a 100 to 1 chance that the fish composing each experiment were drawn from a non-homogenous population. Therefore the assumption that the groups of fish composing the different experiments were of different conditions is probably valid, making it advisable to average the percentage mortalities of the various experiments.

dall, 1937, p. 426). These calculations gave a value for P of 0.55 for the difference in shedding and of 0.10 for the difference in deaths. Both values indicate that the slightly smaller average percentages for square-ended tags are the result of chance.

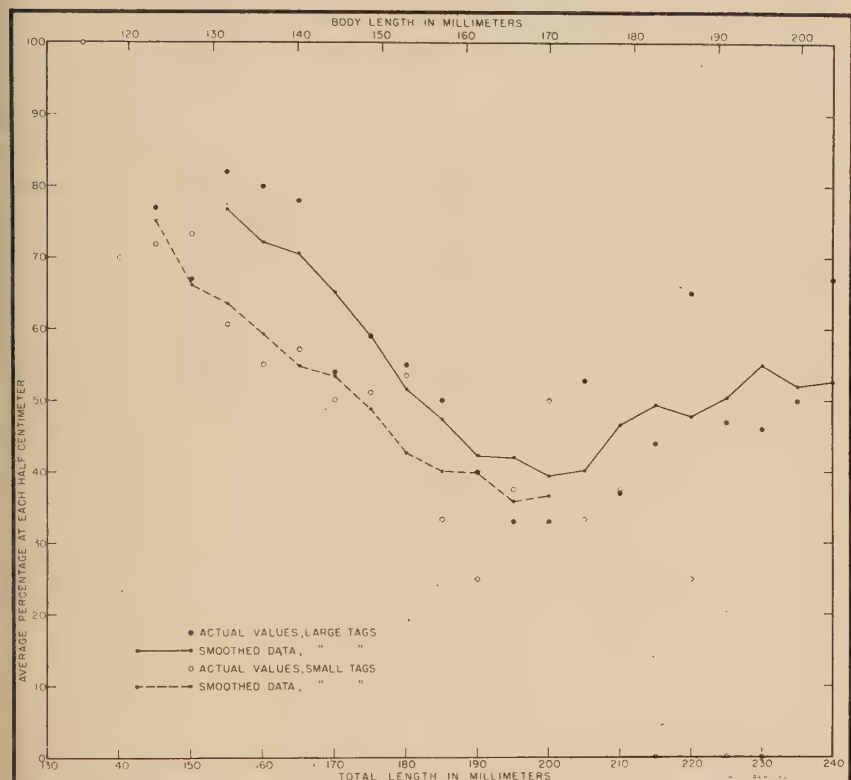


FIG. 7. The percentage of fish which died and shed at each half centimeter of length in each experiment was averaged to give each experiment equal weight. Fish over 240 mm. total length were discarded as their numbers were too few to be reliable. The lines were fitted by smoothing the data by a moving average of five. The mortality of controls has not been deducted.

TABLE 3

Experiment number	SMALL SQUARE-ENDED TAGS			SMALL ROUND-ENDED TAGS		
	Number of fish tagged	Percentage that shed tags	Percentage that died bearing tags	Number of fish tagged	Percentage that shed tags	Percentage that died bearing tags
1938-3	196	9.2	10.2	268	12.7	14.2
1939-4	196	1.5	94.4	199	2.0	89.5
1939-5	297	5.4	71.0	295	4.1	75.2
Average		5.4	58.5		6.3	59.6

SCALPEL-FORCEP METHOD VERSUS TAGGING GUN METHOD OF INSERTING TAGS

There has been some question as to the relative merits of the tagging gun method of inserting tags into fish as compared with the scalpel-forcep method. To throw some light upon this subject both methods were used in three experiments on medium sized fish (Tables 1 and 4). The technique as practiced in California was followed when inserting tags by the scalpel-forcep method. A tagging gun, borrowed from Dr. J. L. Hart of Nanaimo, British Columbia, was used to tag fish by the tagging gun method. The results are shown in table 4. In every case the scalpel-forcep method gave the better results. Part of this difference may have been due to inexperience in handling the gun but we cannot feel that it is entirely responsible. Experiment 1939-2 should possibly be excluded from the comparison for reasons stated previously. However, its trend is the same as the other two experiments and its inclusion does not alter the conclusions drawn. In experiments 1939-1 and -3 the shedding was much greater among fish tagged with the gun than with the scalpel and forceps, whereas the percentage of fish which died differed by less than 5. A chi-square test was

TABLE 4

Experiment number	Scalpel-forcep method			Tagging gun method		
	Number of fish tagged	Percentage that shed tags	Percentage that died bearing tags	Number of fish tagged	Percentage that shed tags	Percentage that died bearing tags
1939-1-----	148	3.4	65.6	142	15.5	70.4
1939-2-----	131	2.3	91.6	153	3.9	94.1
1939-3*-----	90	3.3	3.4	75	25.3	6.7
Average-----	-----	3.0	53.5	-----	14.9	57.1

* Conditioned fish.

applied to each of the three experiments. The resulting chi-squares were treated as in the previous section to obtain a measure of the significance of the differences between the averages in table 4. For the difference in deaths produced by the two methods of tagging the value for P is 0.49, indicating the differences are merely the result of sampling errors. For the difference in the amount of shedding the value for P is less than 0.0005, indicating significance for the higher percentage of tags shed under the tagging gun method. Shedding appears, therefore, to be an important factor in the difference between the two tagging methods. This is probably accounted for by the fact that the tagging gun made larger incisions in the fish and did not push the tag as far into the body cavity as does the scalpel-forcep method.

Hart (1939) found no significant difference between the two methods in his work in British Columbia. The difference resulting from the two techniques unquestionably depends upon the circumstances under which they are executed, the skill of the operators, the refinement of the tagging instruments and the sizes of the fish tagged. California investigators use a scalpel with a very narrow, thin remov-

able blade. The blade is changed frequently. The forceps used to insert the tags have thin shanks and are non-corrosive. Furthermore, the tagging operation is performed by three people. In Oregon and in British Columbia where the gun is in general use the tagging is done by a single man. When using the scalpel-forcep method under such circumstances it would probably be impossible to handle the fish as carefully as when three men are available. Therefore a higher mortality, equal to that resulting from the tagging gun technique, could be expected with the scalpel-forcep method if tagging was done by only one man.

SHEDDING OF TAGS

Shedding has been mentioned from time to time and the amount of shedding in the different experiments is shown in table 1. When making post-mortem examinations of tagged fish which had been held in the live box some tags were found in all stages of being shed. The end of the tag in such cases was usually found lodged in the body wall, presumably in the old incision. Tags have been found with an end entirely outside of the fish. Just how long shedding takes place is not known but the number shed after two months was insignificant. After tagged fish had been held for five months, however, some tags were found in various stages of working through the body wall. No fish were held longer than five months.

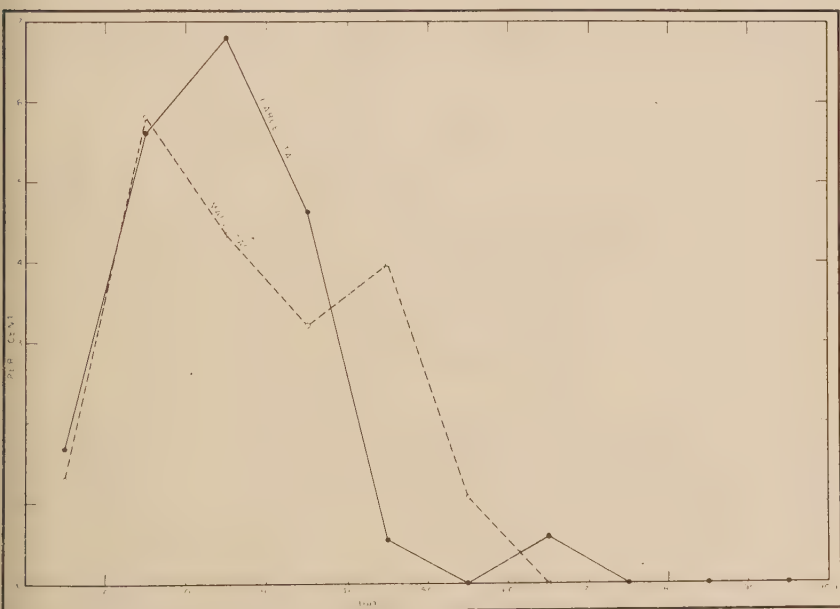


FIG. 8. Number of tags recovered by a magnet from the bottom of the live boxes over each 10-day period expressed as percentage of the average number of tagged fish remaining alive over the same periods. Percentages for large and small tags calculated separately. All experiments combined totaling 82 large tags and 171 small tags. Cadmium plated tags and tags applied with the tagging gun are excluded.

The time when the greatest shedding occurs could not be definitely determined as it was impossible to be certain of recovering all shed tags from the bottom of the live box within a reasonable time after they had been lost by the fish. A magnet was frequently dragged over the bottom of each compartment but because of an accumulation of sediment all of the tags could not be recovered by this method. Frequently turbidity of the water and corrosion of the tags prevented them from being seen.

Disregarding cadmium tags and tags applied with a tagging gun, 77.4 per cent of the large tags and 67.6 per cent of the small tags which were shed were recovered from the bottom of the fish compartments. The number of these tags recovered over each ten-day period was divided by the average number of tagged fish remaining alive during the same ten-day periods. The resulting figures were converted to percentage and plotted separately for large and small tags as shown in figure 8. The figure indicates that shedding is inconsiderable after two months have elapsed.

Very likely shedding is partly a function of the care, or lack of care, in the tagging procedure. There seems to be some evidence that there was more shedding when inexperienced personnel did the tagging than when more experienced individuals did it. An unnecessarily large incision is probably an important cause of shedding. The location of the incision is possibly another factor. The cut must be made back far enough to allow ample room in front of it for the tag and yet it must not be made where the body cavity is narrower than the tag. If the tag moves at all within the body cavity of the fish it most likely moves ventrally to some extent due to its own weight. Therefore if it is inserted a little above the floor of the body cavity it has less chance of working out through the incision than if it is inserted very near the ventral surface of the fish. If the cut is made too high the tag will lodge within the back muscles and probably shed more easily than if placed within the body cavity (Hart and Tester, 1937.2). Care must be exercised in placing the tag within the fish. The tag should be pushed cleanly through the body wall so that it rests a little forward of the incision. To prevent internal injuries, more caution is necessary when tagging small fish because of their smaller body cavities.

CADMIUM-PLATED TAGS

A cadmium-plating factory, thinking cadmium would serve better than nickel, plated a few tags free of charge. These tags were tried in experiments 1939-6 and -7. In each experiment 97 conditioned fish were tagged with large cadmium-plated tags (Tables 1 and 5). Fish tagged with large nickel-plated tags were controls. None of the fish bearing cadmium-plated tags lived more than a few days whereas the controls survived satisfactorily. It is clear that cadmium-plated tags are entirely unsatisfactory for internal use in sardines. Several cadmium compounds are known to be toxic and apparently one or more of these are formed in the body of the sardine.

TABLE 5

Type of tag	Experi- ment number	Number of fish tagged	Percentage that lived to end of experiment	Percentage that shed tags	Percentage that died bearing tags	Mortality due to tagging
Large cadmium plated tags-----	1939-6	97	0.0	0.0	100.0	100.0
	1939-7	97	0.0	3.1	96.9	100.0
Large nickel-plated tags-----	1939-6	98	42.8	8.2	49.0	57.2
	1939-7	150	13.3	31.3	55.4	86.7
Small nickel plated tags-----	1939-6	74	50.0	20.3	29.7	50.0
	1939-7	146	26.7	58.2	15.1	73.3

ENCYSTING OF TAGS

Whenever tagged fish were found dead in the live box compartments their body cavities were opened to determine the location of the tag as well as its number. At the time the experiments were concluded all remaining tagged fish were also examined to determine the fate of their tags. From these observations it was found that the tags may lodge in any number of places within the body cavity of the fish. As early as ten days after being put into sardines, tags have been found attached to the tissues against which they rest. Eventually, most of the tags become firmly attached.

Some of the places where tags have been found attached are along the ventral and lateral body wall, under and within the air bladder or lobe of the liver, within or against fat bodies, the gonads, the intestine or the mesentary.

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MEASUREMENT OF THE LOSSES IN THE RECOVERY OF SARDINE TAGS

BY FRANCES N. CLARK AND JOHN F. JANSSEN, JR.

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INTRODUCTION

Purpose of the Investigation

For many years fisheries students throughout the world have been tagging fish to better understand migrations and more recently to measure the intensity of fishing. In most of these programs the recovery of tags has depended on the tag being observed on a recaptured fish and returned by the observer to the investigator. Under this method a certain number of tagged fish are recaptured but the tag is not returned to the proper authority, either because it was not seen or because the finder was not sufficiently interested. The proportion of tags thus lost is not known. To know its magnitude would aid materially in the analysis of results, but to measure its fluctuations between time intervals is of even greater importance. If the loss of recaptured tags is a fairly constant factor, calculations can be carried on under the assumption that this loss is operating equally at all times. If, on the other hand, the loss of recaptured tags varies from time to time this variation may be sufficient to affect seriously the conclusions drawn from tagging experiments.

The method of recovery of tags used for marking the sardine, *Sardinops caerulea*, along the Pacific coast of North America lends itself

to a measure of the magnitude of this loss and its variation between time intervals. The tags are recovered on electromagnets installed in meal lines of more than half of the reduction units operated by the sardine processing plants of California (Fry, 1937). These reduction units treat whole sardines, or the offal and discarded fish remaining after canning, in an elaborate process which extracts the oil and dries and grinds the remaining solid matter into fish meal. (Hatton and Smalley, 1938). The magnet used to recover sardine tags is placed in the meal line so that the dried meal passes over its face before going through the grinder. Thus, the number of sardine tags recovered depends on the proportion of tags which after entering the plant are carried through to the magnet, on the efficiency with which the magnet operates, and on the care used by the reduction plant employees in clearing the tags and other metal scrap from the magnet.

Experience has shown that all of these are variable factors. A measure of their variation, together with the percentage that the number of tags recovered constitutes of the total tags entering the plants, was the purpose of this investigation. The resulting value which is the percentage that may be expected to be recovered at all plants with magnets in each port has been termed the port efficiency.

Port efficiency measures, therefore, the proportion of tags recovered from sardine processing plants where magnets are installed. It gives no measure of the number of tags not recovered from the plants where no magnets are installed nor of the tags not recovered from sardines sold to the fresh fish trade or used for bait. This difficulty can be over-

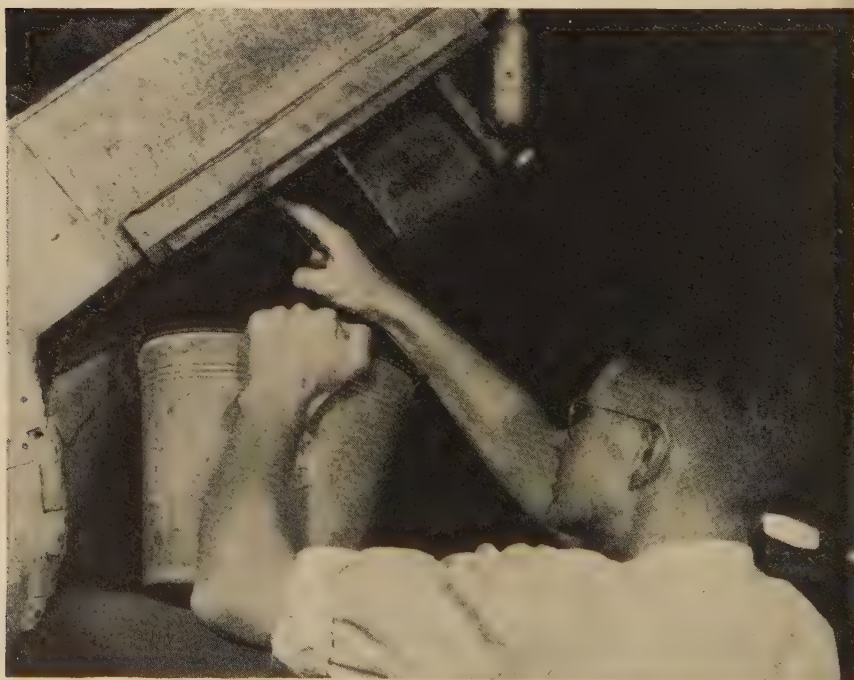


FIG. 1. Removing metal scrap from a magnet installed in a reduction plant. Photo by D. H. Fry, Jr., October, 1939.

come, however, by determining the theoretical number of tags occurring in each ton of fish processed by plants with magnets. From this value the entire number of tags occurring in the total season's catch can be calculated.

Summary of Results

Two sizes of tags are used in the sardine marking experiments. (See "Effect of internal tags upon sardines".) The investigation has demonstrated that the efficiency of recovery for small tags is about 6 per cent less than for large tags and that the difference is statistically significant.

The port efficiency for both sizes of tags varies from port to port and from season to season. The simplest calculation of port efficiency for plants with magnets is the percentage of tags recovered from all test tags introduced into all plants. This is termed method B and gives reliable values. The percentage values thus derived are as follows:

	<i>San Francisco</i>		<i>Monterey</i>		<i>San Pedro</i>	
	<i>Small Tags</i>	<i>Large Tags</i>	<i>Small Tags</i>	<i>Large Tags</i>	<i>Small Tags</i>	<i>Large Tags</i>
1938-39-----	57.23	71.20	74.32	77.95	64.16	69.80
1939-40-----	55.92	61.51	62.69	67.06	69.94	76.44

The efficiency of recovery of tags varies between plants and from week to week within plants.

As high a percentage of tags is recovered from the reduction of offal from sardines used for canning as from the reduction of whole sardines.

Ninety per cent or more of tags recovered from the plants will be returned within ten days. Most of the remainder will be returned over an interval of 100 days or more. Approximately 1 per cent will not be recovered until the following season and 0.1 per cent until the second season after entering the plant.

Monthly tests of the chances of tag recovery give reliable measures of port efficiency.

METHODS

There are three important factors which may cause a failure to recover tags. These are: (1) The tags may be lost in the machinery of the plant before they reach the meal lines where they will come in contact with the magnet. (2) The magnet may not attract and retain all tags passing over it. (3) The tags may be lost during the process of clearing the tags and other metal scrap from the magnet.

Each of these factors has been found to vary between plants. Loss in the machinery is dependent on the construction of the reduction unit. Some plants are so constructed that tags pass through quickly and are recovered within a few days. In other units many nooks and crannies abound where tags are lost completely or later dislodged to appear weeks and even months after entering the plant.

Under the second factor, the magnet may not retain all tags because a satisfactory installation is not possible due to the construction of the plant, or the magnet may not work at maximum efficiency due to temporary defects in wiring, etc. Also, much metal collects on the magnet in addition to fish tags. If the plant is operating for many hours and the magnet is not cleared during that time, so much metal collects that no more can be retained. When this occurs either a large amount of

metal drops from the magnet and is lost into the grinder or meal fills in the crevices between the collected metal scraps and forms an insulation so that all subsequent metal passes over the magnet.

The personal reactions of the reduction plant operators materially influence the last factor producing tag loss. In plants which are efficiently run, more tags are recovered because the men work under more satisfactory conditions. They, therefore, take more interest in the operations and make a much greater and more intelligent effort to care for the magnets and recover all tags retained on them.

Since we wished only to determine the total amount of tag loss, our tests were not designed to measure which of the above factors were most important in the failure to recover tags. Preliminary work on this investigation was begun in 1936-37 and continued on a small scale in 1937-38. During these two seasons 10 or 20 tags were placed in dead sardines in the pit where fish and offal are accumulated before entering the reduction plant. The results of these few preliminary tests indicated that the proportion of tags which will be recovered varies between plants and between time intervals at the same plant. Consequently in 1938-39, a detailed investigation was inaugurated. At Monterey and San Pedro, 50 small and 50 large tags were placed in each plant once each week throughout the sardine season. In a few instances certain plants did not operate every week so that all plants were not tested with an equal thoroughness, but the more frequently a plant operated, the more frequently its efficiency was tested. As in the previous seasons, each tag was placed in a sardine and the fish were either scattered through the reduction pit or dropped into the screw conveyor which carries the fish to the reduction machinery. Had it been possible the tags should have been placed in fish in the hold of the fishing boats before the fish were unloaded. This would have included in the test a measurement of the failure to recover tags through an occasional loss in the unloading process of a fish bearing a tag. Due to the objections of the plant operators this test could not be made. In the majority of the California plants sardines are canned as well as reduced to meal and oil and the operators feared lawsuits if a test tag should inadvertently get into a can of sardines. The tests had to be conducted, therefore, beyond the canning lines at the entrance to the reduction unit.

At San Francisco the sardine processing plants are scattered along so many miles of San Francisco Bay that it was not possible to make a weekly measure of the chances of tag recovery. Consequently, the tests were made only once a month in 1938-39 and in some cases even this schedule could not be maintained. Some plants were checked only once or twice within the season. Due to a misunderstanding, small and large tags were not tested simultaneously at San Francisco, but 100 small or 100 large tags were used in each trial.

The tests resulted in two kinds of tags entering the plants and being recovered on the magnets. Those tags which were placed in dead fish and introduced into the reduction unit to test the efficiency of tag recovery are called "test" tags. Those tags which were placed in live fish released at sea, and later caught by fishermen and delivered to the plants are termed "live" tags. We propose to calculate the proportion of these live tags which are returned during the process of recovery in the reduction plants by means of the number of test tags returned in the same process.

CALCULATIONS OF PORT EFFICIENCY FOR THE 1938-39 SEASON

Differences Between the Recovery of Large and Small Tags

It is reasonable to expect that the small tags will be lost more frequently in the machinery of the reduction plant, that they will not be readily held on the face of the magnet, and that they will be overlooked more often when the tags are cleared from the magnet and sorted from other metal scrap than will the large tags. Thus the percentage of recovery of small tags should be less than of large tags. Such proved to be the case, as is shown in table 1. This table, giving the number of test tags recovered from all experiments run in 1938-39, shows that more large tags were recovered at each port than small tags. The greatest difference, 14 per cent, was at San Francisco, and probably resulted in part from the inadequacy of the tests at that port. At Monterey the difference was 4 per cent and at San Pedro, 6 per cent. For all ports combined the difference was also 6 per cent.

TABLE 1

Percentage of Small and Large Test Tags Recovered in the 1938-39 Season

	Number of tags used	Number of tags recovered	Per cent of tags recovered	Difference	Standard error
San Francisco					
Small tags.....	3,383	1,936	57.23		
Large tags.....	2,892	2,059	71.20	13.97	± 1.20
Monterey					
Small tags.....	9,836	7,310	74.32		
Large tags.....	9,887	7,707	77.95	3.63	$\pm .61$
San Pedro					
Small tags.....	5,089	3,265	64.16		
Large tags.....	5,000	3,490	69.80	5.64	$\pm .93$
All Ports					
Small tags.....	18,308	12,511	68.34		
Large tags.....	17,779	13,256	74.56	6.22	$\pm .47$

In each of the four comparisons the difference between the percentage of recovery of large and small tags exceeds its standard error by 6 or more times. These differences must be interpreted, therefore, as significant and not merely the result of errors of random sampling. The standard error of the percentage of recovery of each type of tag was calculated from the formula for the standard error of the binomial distribution, $\sqrt{\frac{pq}{n}}$ where p is the percentage of tags recovered, q the percentage of tags not recovered and n the total number of tags used. The standard error of the difference is the square root of the sum of the squares of the standard errors of the two percentages compared. Similar tests of the significance of the differences in the recovery of large and small tags based on the chi-square formula gave values for P of less than 0.001. This also demonstrates that large tags are recovered significantly more often than are small tags.

Factors Affecting Methods of Calculation

The calculation of the port efficiency for the recovery of live tags should presumably be based not only on the recovery of test tags but also on the recovery of live tags. If the live tags are so distributed throughout the fishing grounds that the chances are equal that any fisherman may catch a tagged sardine and return it to any plant in the port, then the percentage of test tags recovered at all plants can be used to measure the percentage of live tags which would be recovered at all plants in the port. But, on the other hand, the live tags may not be equally available to all fishermen and one fisherman may have a greater chance of catching a tagged fish and returning it to a given plant than has another fisherman fishing for a different reduction unit. Under the second condition, the percentage of test tags recovered at each plant must be used to weight the number of live tags recovered at the plant and the port efficiency calculated from the summation of these weighted values.

In addition to the complications introduced by the equal or unequal chances of live tags entering each of the reduction units, the total recovery of test tags in the port may be affected by the varying efficiency of the tag recoveries between plants. If a plant has a low efficiency of tag recovery and handles large tonnages it should be given more weight in determining the port efficiency than should a plant having a high efficiency but processing only small tonnages. The converse would be equally true. Also, the efficiency of any given plant may vary throughout the season and perhaps its efficiency for tag recoveries should be weighted by the tonnages handled at time intervals shorter than the entire season.

To test the influence of these various factors the port efficiency for the 1938-39 sardine season was calculated from the Monterey and San Pedro data in four different ways. These methods have been designated as A, B, C and D, and are explained below. The same method of calculation was applied to both large and small tags and consequently there were eight calculations both for Monterey and San Pedro.

During the 1938-39 season the efficiency of tag recovery was tested weekly, which was a very time-consuming procedure. To determine if fewer tests in a season would give sufficiently reliable results, calculations A, B, C and D were also applied to the San Pedro data, selecting only the test made in the midpoint of the month. At Monterey calculations A, B, and C were also applied to the midmonthly test of the 1938-39 data. These monthly tests as contrasted with the weekly tests have been termed A', B', C' and D'. Because only monthly tests were made at San Francisco, comparable calculations could not be made. Calculations A', B' and C' have been carried out for San Francisco.

The similarities or differences in the port efficiencies derived from these different calculations should give some measure of the importance of the factors influencing the percentage of tags which will be recovered.

Weekly Tests

A *Calculations on the basis of the number of live tags per plant and the number of test tags per plant*

In this method, the percentage efficiency of tag recovery for each plant was determined by the percentage of test tags recovered at the

plant within the season. The number of live tags recovered at the plant was then weighted to a theoretical total number which would have been recovered, if recovery efficiency had been 100 per cent, by the ratio: percentage efficiency of recovery/live tags recovered = 100 per cent efficiency/theoretical total live tags recovered. The total live tags recovered at the port, expressed in percentage of the theoretical total live tags recovered, constitutes the port efficiency. The results of these calculations are given for Monterey in table 2, and for San Pedro in table 3.

It is evident that the paucity of numbers of live tags recovered precluded any attempts to calculate port efficiency for a shorter time interval than the entire season. No simple method of measuring the significance

TABLE 2

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at Monterey by Method A

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
-----	36.24	2	5.52	47.74	3	6.28
-----	67.52	12	17.77	72.33	23	31.80
-----	86.02	12	13.95	88.94	10	11.24
-----	82.43	5	6.07	89.59	6	6.70
-----	87.06	8	9.19	91.08	11	12.08
-----	82.69	19	22.98	87.26	23	26.36
-----	74.46	7	9.40	81.07	9	11.10
-----	79.55	22	27.66	77.55	25	32.24
-----	71.46	6	8.40	67.72	13	19.20
-----	61.95	10	16.14	66.86	7	10.47
Totals-----		103	137.08		130	167.47
Port efficiency-----	$\frac{103 \times 100}{137.08} = 75.14\%$			$\frac{130 \times 100}{167.47} = 77.63\%$		

TABLE 3

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at San Pedro by Method A

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
-----	80.24	26	32.40	85.44	35	40.96
-----	52.95	13	24.55	56.59	17	30.04
-----	73.32	7	9.55	77.59	16	20.62
-----	49.24	7	14.22	58.60	3	5.12
-----	72.62	6	8.26	74.30	6	8.08
-----	49.67	8	16.11	52.15	21	40.27
-----	60.90	3	4.93	67.17	5	7.44
-----	72.77	9	12.37	85.34	13	15.23
Totals-----		79	122.39		116	167.76
Port efficiency-----	$\frac{79 \times 100}{122.39} = 64.55\%$			$\frac{116 \times 100}{167.76} = 69.15\%$		

of the percentage port efficiency based on method A is available. The probable variation in the efficiency of the recovery of test tags at each plant can be measured, but the variation in the number of live tags recovered cannot, since the number and distribution of the tags on the fishing grounds is not known.

B Calculations on the basis of total number of test tags per port

This method of calculating port efficiency is the simplest of all, and if found to be sufficiently reliable would be the most convenient to use. It consists merely of determining the percentage of all test tags recovered in relation to all test tags used. The results are shown for Monterey in table 4 and for San Pedro in table 5. These two tables demonstrate that there is considerable difference between plants in the efficiency with which tags will be recovered. The standard errors of the port efficiency percentages have been calculated from the formula, $\sqrt{\frac{pq}{n}}$.

TABLE 4

Calculation of Port Efficiency for 1938-39 for the Recovery of Tags at Monterey by Method B

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent of tags recovered	Standard error	Number of tags used	Number of tags recovered	Per cent of tags recovered	Standard error
1.....	792	287	36.24	-----	798	381	47.74	-----
2.....	939	634	67.52	-----	947	685	72.33	-----
3.....	944	812	86.02	-----	931	828	88.94	-----
4.....	831	685	82.43	-----	845	757	89.59	-----
5.....	935	814	87.06	-----	942	858	91.08	-----
6.....	1,531*	1,266	82.69	-----	1,538*	1,342	87.26	-----
7.....	744	554	74.46	-----	745	604	81.07	-----
8.....	1,340*	1,066	79.55	-----	1,345*	1,043	77.55	-----
9.....	939	671	71.46	-----	948	642	67.72	-----
10.....	841	521	61.95	-----	848	567	66.86	-----
Totals.....	9,836	7,310	74.32	± .44	9,887	7,707	77.95	± .42

* This plant had two reduction units and each unit was tested independently. Because it was not possible to relate live tags to the specific unit the tests were combined.

TABLE 5

Calculation of Port Efficiency for 1938-39 for the Recovery of Tags at San Pedro by Method B

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent of tags recovered	Standard error	Number of tags used	Number of tags recovered	Per cent of tags recovered	Standard error
1.....	764	613	80.24	-----	783	669	85.44	-----
2.....	695	368	52.95	-----	698	395	56.59	-----
3.....	596	437	73.32	-----	598	464	77.59	-----
4.....	593	292	49.24	-----	587	344	58.60	-----
5.....	599	435	72.62	-----	498	370	74.30	-----
6.....	749	372	49.67	-----	744	388	52.15	-----
7.....	399	243	60.90	-----	396	266	67.17	-----
8.....	694	505	72.77	-----	696	594	85.34	-----
Totals.....	5,089	3,265	64.16	± .67	5,000	3,490	69.80	± .65

Calculations on the basis of the number of test tags per plant per season weighted by the tonnage per plant per season

Tables 4 and 5 show that the efficiency of tag recovery varies much between plants at each port. An adjustment for the number of tons of arduines handled by the different plants seemed advisable. This was done by weighting the plant percentage by the plant tonnage and averaging the weighted percentages. This gave the port efficiency based on the number of test tags recovered per plant in relation to the tonnage processed per plant. Tables 6 and 7 give the results for Monterey and San Pedro.

TABLE 6

Calculation of Port Efficiency for 1938-39 for the Recovery of Tags at Monterey by Method C

Plant	Tons processed	SMALL TAGS		LARGE TAGS	
		Per cent of test tags recovered	Tons times per cent	Per cent of test tags recovered	Tons times per cent
1.....	10,028	36.24	363,414.72	47.74	478,736.72
2.....	20,166	67.52	1,361,608.32	72.33	1,458,606.78
3.....	9,859	86.02	848,071.18	88.94	876,859.46
4.....	9,697	82.43	799,323.71	89.59	868,754.23
5.....	18,209	87.06	1,585,275.54	91.08	1,658,475.72
6.....	20,877	82.69	1,726,319.13	87.26	1,821,727.02
7.....	6,945	74.46	517,124.70	81.07	563,031.15
8.....	24,631	79.55	1,959,396.05	77.55	1,910,134.05
9.....	13,468	71.46	962,423.28	67.72	912,052.96
0.....	14,660	61.95	908,187.00	66.86	980,167.60
Totals.....	148,540		11,031,143.63		11,528,545.69
Port efficiency.....		$\frac{11,031,143.63}{148,540} = 74.26\%$		$\frac{11,528,545.69}{148,540} = 77.61\%$	

TABLE 7

Calculation of Port Efficiency for 1938-39 for the Recovery of Tags at San Pedro by Method C

Plant	Tons processed	SMALL TAGS		LARGE TAGS	
		Per cent of test tags recovered	Tons times per cent	Per cent of test tags recovered	Tons times per cent
1.....	17,541	80.24	1,407,489.84	85.44	1,498,703.04
2.....	20,821	52.95	1,102,471.95	56.59	1,178,260.39
3.....	5,520	73.32	404,726.40	77.59	428,296.80
4.....	7,986	49.24	393,230.64	58.60	467,979.60
5.....	5,222	72.62	379,221.64	74.30	387,994.60
6.....	13,080	49.67	649,683.60	52.15	682,122.00
7.....	3,887	60.90	236,718.30	67.17	261,089.79
8.....	16,055	72.77	1,168,322.35	85.34	1,370,133.70
Totals.....	90,112		5,741,864.72		6,274,579.92
Port efficiency.....		$\frac{5,741,864.72}{90,112} = 63.72\%$		$\frac{6,274,579.92}{90,112} = 69.63\%$	

D Calculations on the basis of the number of test tags per plant per month weighted by the tonnage per plant per month

The variations in the percentages of test tags recovered from plant to plant are shown in tables 2-7, but there still remain to be considered the weekly and monthly variations within each plant. The number of tests run precludes the possibility of presenting the details for each plant. Data for two plants are shown in tables 8 and 9. Table 8 is an example of maximum variation and table 9 is an example of minimum variation.

TABLE 8

Weekly Number of Test Tags Used and Recovered at Plant 1 at Monterey, Illustrating a Maximum Variation in Efficiency of Tag Recovery

Date	SMALL TAGS			LARGE TAGS		
	Number of tags used	Number of tags recovered	Per cent recovered	Number of tags used	Number of tags recovered	Per cent recovered
August 20, 1938.....	50	1	2.00	50	21	42.00
August 23, 1938.....	50	5	10.00	50	6	12.00
September 1, 1938.....	50	22	44.00	50	22	44.00
September 15, 1938.....	50	44	88.00	50	41	82.00
September 20, 1938.....	50	14	28.00	50	24	48.00
September 28, 1938.....	50	22	44.00	49	20	40.82
October 22, 1938.....	47	34	72.34	49	37	75.51
October 25, 1938.....	49	10	20.41	50	18	36.00
November 1, 1938.....	49	28	57.14	50	41	82.00
November 12, 1938.....	49	29	59.18	50	39	78.00
November 15, 1938.....	50	29	58.00	50	34	68.00
November 22, 1938.....	49	19	38.78	50	27	54.00
December 14, 1938.....	49	0	0	50	2	4.00
December 30, 1938.....	50	16	32.00	50	26	52.00
January 13, 1939.....	50	10	20.00	50	15	30.00
January 20, 1939.....	50	4	8.00	50	8	16.00
Totals.....	792	287	36.24	798	381	47.74

TABLE 9

Weekly Number of Test Tags Used and Recovered at Plant 4 at Monterey, Illustrating a Minimum Variation in Efficiency of Tag Recovery

Date	SMALL TAGS			LARGE TAGS		
	Number of tags used	Number of tags recovered	Per cent recovered	Number of tags used	Number of tags recovered	Per cent recovered
August 19, 1938.....	50	44	88.00	50	47	94.00
August 23, 1938.....	50	35	70.00	50	42	84.00
September 2, 1938.....	50	34	68.00	50	43	86.00
September 16, 1938.....	50	40	80.00	50	48	96.00
September 20, 1938.....	49	42	85.71	49	43	87.76
September 28, 1938.....	48	39	81.25	50	44	88.00
October 18, 1938.....	47	39	82.98	50	48	96.00
October 25, 1938.....	48	42	87.50	50	46	92.00
November 1, 1938.....	48	43	89.58	50	48	96.00
November 12, 1938.....	48	46	95.83	50	47	94.00
November 15, 1938.....	49	46	93.88	49	47	95.92
November 22, 1938.....	49	40	81.63	48	43	89.58
December 13, 1938.....	48	43	89.58	50	42	84.00
December 21, 1938.....	50	42	84.00	49	44	89.80
December 31, 1938.....	50	44	88.00	50	49	98.00
January 20, 1939.....	50	31	62.00	50	37	74.00
January 24, 1939.....	47	35	74.47	50	39	78.00
Totals.....	831	685	82.43	845	757	89.59

To determine if these variations within plants should be considered in the measurements of port efficiency, calculations were made by method D. This involved weighting the monthly efficiency of each plant by the monthly tonnage processed by the plant, and summing these weighted values for all plants for the season. The sums were then divided by the total tonnage processed at the port. The results give port efficiencies as follows:

	Monterey	San Pedro
Small Tags -----	72.93 per cent	63.78 per cent
Large Tags -----	76.31 per cent	69.93 per cent

Monthly Tests

A' Calculations on the basis of the number of live tags per plant and the number of test tags per plant

This calculation was made by the same procedure used in method A except that the efficiency of test tag recovery for a plant was based on only the test tags used in the midweek of each month. The purpose of this and the succeeding calculations was to determine the feasibility of testing the efficiency of tag recovery monthly instead of weekly. In this series the San Francisco data have been included, as somewhat incomplete monthly tests were made at that port. The results are given in tables 10, 11 and 12.

TABLE 10

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at San Francisco by Method A'

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
1 -----	85.93	8	9.31		17	
2 -----		3		78.00	2	2.56
3 -----		1		84.00	5	5.95
4 -----	18.59	4	21.52		14	
5 -----	81.21	8	9.85	91.22	22	24.12
6 -----	54.91	4	7.28	69.33	9	12.98
7 -----	50.88	7	13.76	85.33	9	10.55
8 -----	75.63	10	13.22	86.00	15	17.44
9 -----	41.00	2	4.88	39.26	7	17.83
10 -----	42.42	4	9.43	67.00	13	19.40
11 -----	63.33	5	7.90	82.91	6	7.24
12 -----	73.00	6	8.22	77.00	9	11.69
13 -----	28.43	0		38.19	4	10.47
14 -----	38.33	6	15.65	58.33	14	24.00
15 -----	64.65	2	3.09	85.00	5	5.88
Totals -----		66 ¹	124.11		120 ²	170.11
Port efficiency -----		$\frac{66 \times 100}{124.11} = 53.18\%$			$\frac{120 \times 100}{170.11} = 70.54\%$	

¹ Omitting plants 2 and 3.

² Omitting plants 1 and 4.

TABLE 11

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at Monterey by Method A'

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
1.....	26.09	2	7.67	38.67	3	7.76
2.....	63.39	12	18.93	69.57	23	33.06
3.....	89.63	12	13.39	86.52	10	11.56
4.....	82.59	5	6.05	87.88	6	6.83
5.....	86.05	8	9.30	96.66	11	11.38
6.....	82.97	19	22.90	85.28	23	26.97
7.....	75.00	7	9.33	84.80	9	10.61
8.....	78.98	22	27.86	80.15	25	31.19
9.....	80.07	6	7.49	72.67	13	17.89
10.....	48.99	10	20.41	53.67	7	13.04
Totals.....		103	143.33		130	170.29
Port efficiency.....	$\frac{103 \times 100}{143.33} = 71.86\%$			$\frac{130 \times 100}{170.29} = 76.34\%$		

TABLE 12

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at San Pedro by Method A'

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
1.....	81.85	26	31.77	84.40	35	41.47
2.....	63.45	13	20.49	71.89	17	23.65
3.....	59.44	7	11.78	66.00	16	24.24
4.....	39.59	7	17.68	53.14	3	5.65
5.....	80.67	6	7.44	78.23	6	7.67
6.....	46.80	8	17.09	47.60	21	44.12
7.....	63.50	3	4.72	70.92	5	7.05
8.....	67.74	9	13.29	85.94	13	15.13
Totals.....		79	124.26		116	168.98
Port efficiency.....	$\frac{79 \times 100}{124.26} = 63.58\%$			$\frac{116 \times 100}{168.98} = 68.65\%$		

Due to the incompleteness of the tests at San Francisco, table 10 presents some complications. Plants 2 and 3 were not tested for the efficiency of recovery of small tags nor plants 1 and 4 for large tags. Plant 13 recovered no small live tags. Methods of interpolation could have been used to assign an efficiency rating to plants 1 to 4 and to obtain a figure for calculating the theoretical recovery of small tags at plant 13. All such methods, however, introduced additional sampling errors and a simpler calculation seemed preferable. This was carried out by omitting those plants which were not tested for recovery efficiency. Plant 13 was also omitted from the calculations on small tags.

B' Calculations on the basis of the total number of test tags per port

As in method B, this is the simplest of all the calculations. It consists merely in determining the number of test tags put into all plants at the midpoint of each month and the number and percentage recovered. The results are given in tables 13, 14 and 15.

TABLE 13

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at San Francisco by Method B'

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent recovered	Standard error	Number of tags used	Number of tags recovered	Per cent recovered	Standard error
1	199	171	85.93					
2					100	78	78.00	
3					200	168	84.00	
4	199	37	18.59					
5	596	484	81.21		296	270	91.22	
6	397	218	54.91		300	208	69.33	
7	399	203	50.88		300	256	85.33	
8	197	149	75.63		100	86	86.00	
9	100	41	41.00		298	117	39.26	
10	99	42	42.42		100	67	67.00	
11	300	190	63.33		199	165	82.91	
12	100	73	73.00		400	308	77.00	
13	299	85	28.43		199	76	38.19	
14	300	115	38.33		300	175	58.33	
15	198	128	64.65		100	85	85.00	
Totals	3,383	1,936	57.23	± .85	2,892	2,059	71.20	± .84

TABLE 14

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at Monterey by Method B'

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent recovered	Standard error	Number of tags used	Number of tags recovered	Per cent recovered	Standard error
1	299	78	26.09		300	116	38.67	
2	295	187	63.39		299	208	69.57	
3	299	268	89.63		282	244	86.52	
4	293	242	82.59		297	261	87.88	
5	294	253	86.05		299	289	96.66	
6	593	492	82.97		598	510	85.28	
7	300	225	75.00		296	251	84.80	
8	547	432	78.98		549	440	80.15	
9	296	237	80.07		300	218	72.67	
10	296	145	48.99		300	161	53.67	
Totals	3,512	2,559	72.86	± .75	3,520	2,698	76.65	± .71

TABLE 15

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at San Pedro by Method B'

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent recovered	Standard error	Number of tags used	Number of tags recovered	Per cent recovered	Standard error
1-----	248	203	81.85		250	211	84.40	
2-----	249	158	63.45		249	179	71.89	
3-----	249	148	59.44		250	165	66.00	
4-----	245	97	39.59		239	127	53.14	
5-----	300	242	80.67		248	194	78.23	
6-----	250	117	46.80		250	119	47.60	
7-----	200	127	63.50		196	139	70.92	
8-----	248	168	67.74		249	214	85.94	
Totals....	1,989	1,260	63.35	±1.08	1,931	1,348	69.81	±1.04

C' Calculations on the basis of the number of test tags per plant per season weighted by the tonnage per plant per season

The percentages of tag recovery for each plant on the basis of one test in the middle of each month, given in tables 13, 14 and 15, were used in the C' calculations. These percentages were weighted by the number of tons handled by each plant and the port efficiency determined therefrom. The detailed calculations for San Francisco are shown in table 16. Those for San Pedro are not included as they can be readily calculated from the percentages of table 15 and the tonnages of table 7. The calculations resulted in a port efficiency at San Pedro of 64.02 per cent for small tags and 71.61 per cent for large tags. The C' calculations were not applied to the Monterey data.

TABLE 16

Calculations of Port Efficiency for 1938-39 for the Recovery of Tags at San Francisco by Method C'

Plant	Tons processed	SMALL TAGS		LARGE TAGS	
		Per cent of tags recovered	Tons times per cent	Per cent of tags recovered	Tons times per cent
1-----	10,007	85.93	859 901.51		
2-----	6,605			78.00	515,190.00
3-----	6,696			84.00	562,464.00
4-----	16,747	18.59	311,326.73		
5-----	8,632	81.21	701,004.72	91.22	787,411.04
6-----	6,464	54.91	354,938.24	69.33	448,149.12
7-----	12,620	50.88	642,105.60	85.33	1 076,864.60
8-----	6,447	75.63	487,586.61	86.00	554,442.00
9-----	7,836	41.00	321,276.00	39.26	307,641.36
10-----	6,172	42.42	261,816.24	67.00	413,524.00
11-----	6,518	63.33	412,784.94	82.91	540,407.38
12-----	6,620	73.00	483,260.00	77.00	509,740.00
13-----	6,514	28.43	185,193.02	38.19	248,769.66
14-----	6,632	38.33	254,204.56	58.33	386,844.56
15-----	6,530	64.65	422,164.50	85.00	555,050.00
Totals	121,040		5,697,562.67		6,906,497.72
Port efficiency-----		$\frac{5,697,562.67}{121,040-6,605-6,696} = 52.88\%$		$\frac{6,906,497.72}{121,040-10,007-16,747} = 73.25\%$	

D' Calculations on the basis of the number of test tags per plant per month weighted by the tonnage per plant per month

This calculation was applied to midmonth percentages of test tag recovery for the San Pedro data only. It gives a port efficiency for small tags of 62.93 per cent and for large tags of 70.71 per cent.

Discussion

Not all possible calculations have been made. Had there been enough live tags recovered per plant each month, a refinement would have been a calculation of port efficiency through the weighting of the monthly recovery of live tags by the monthly recovery of test tags. Also the number of test tags recovered per week could have been weighted by the tonnages processed per week and other methods of weighting test tags by tonnages could have been carried out. The similarity in the results of the calculations here presented indicates, however, that further refinements would not be likely to yield additional information.

The port efficiencies as calculated by all the methods are compared for the different ports in table 17. In tables 18 to 20 the differences between each method and all other methods are shown for each port. For San Francisco (Table 18) there are no comparisons between weekly and monthly tests. For Monterey there are two for each size of tag, and for San Pedro there are four. For Monterey (Table 19) according to methods A and A' the measure of port efficiency differs by 3.28 for small tags and by 1.29 for large tags. The B-B' comparisons differ by 1.46 and 1.30 for small and large tags, respectively. The B-B' comparison is of special interest because the significance of this difference can be determined simply. The standard error of the difference for small tags is 0.87 and for large tags, 0.83. Both differences exceed their standard errors by less than two times and are evidently merely the result of chance sampling. A chi-square test gives a value for P of 0.10 for small tags and 0.12 for large tags, indicating a difference as great as these values would occur as the result of random samplings once in ten times. Because the probabilities of recovery of live tags cannot be measured there is no accurate measure of the significance for the A-A' differences. The standard error of the differences would be as great and presumably greater than that for the B-B' difference. From this reasoning the A-A' difference for large tags would be considered insignificant and that for small tags would be left in doubt.

For San Pedro (Table 20), no difference in the eight comparisons between the weekly and monthly tests is as great as 1 except for the C-C' for large tags, which equals 1.98. For the two B-B' comparisons, the standard error of the difference for small tags is 1.27 and for large tags, 1.23. Both of these standard errors are larger than the two differences, 0.81 and 0.01 respectively. A chi-square test gave a value for P of 0.5 for small tags and unity for large tags again indicating, as at Monterey, that the differences resulted merely from random sampling. No analysis of variance can be readily made for any of the weekly-monthly San Pedro comparisons other than the B-B'. All but one, however, are less than the standard error of the difference for the B-B' standard error. From the results of the Monterey and San Pedro calculations on the basis of weekly and monthly tests, we have concluded that reliable port efficiencies for a season can be calculated if the efficiency of recovery is tested once each month.

TABLE 17
Port Efficiency in Percentage as Calculated by Various Methods

METHOD																
SMALL TAGS									LARGE TAGS							
A	A'	B	B'	C	C'	D	D'	A	A'	B	B'	C	C'	D	D'	
San Francisco																
1938-39	53.18		57.23		52.88				70.54		71.20		73.25			
1939-40	59.48		55.92						63.51		61.51					
Monterey																
1938-39	75.14	71.86	74.32	72.86	74.26	72.93		77.63	76.34	77.95	76.65	77.61		76.31		
1939-40		61.61		62.69					66.46		67.06					
San Pedro																
1938-39	64.55	63.58	64.16	63.35	63.72	63.78	62.93	69.15	68.65	69.80	69.81	69.63	71.61	69.93	70.71	
1939-40		66.65		69.94					68.18		76.44					

The comparisons between A, B, C and D indicate also that any method for calculating port efficiency gives results which differ from any other method no more than is to be expected from random sampling. In fact, in none of the 92 comparisons shown in tables 18, 19 and 20 is the difference as great as 3, except for A'-B' (small tags) at San Francisco, and for A-A' (small tags) at Monterey. Evidently the errors in each of the methods are of a compensating nature and are not accumulative. Also the similarity of results for the comparisons of A and A' with all other methods indicate that live tags are equally available to all fishermen on the fishing grounds at the time that sardines bearing live tags are recaptured.

LENGTH OF TIME TAGS REMAIN IN A PLANT

It is of interest to know how quickly a live tag will be recovered after it has been caught by a fisherman and delivered to a plant. This is of special importance in determining the locality in which a tagged fish was caught. If a tag will be recovered from a plant on the same day it has been caught by the fisherman, the tagged fish can perhaps be assigned to one of the fishing grounds on which the fishermen were operating on the day the tag is recovered. But if there is any delay in recovery, the possibility of relating live tags to definite fishing grounds becomes difficult. The test tags used in the 1938-39 experiments give a reliable measure of the length of time required for a tag to work through a plant and be recovered.

TABLE 18

Differences Between the Resulting Values for Port Efficiency for 1938-39 at San Francisco as Calculated by Various Methods

Method	SMALL TAGS			Method	LARGE TAGS		
		A'	B'			A'	B'
	Value	53.18	57.23		Value	70.54	71.20
B'-----	57.23	4.05		B'-----	71.20	.66	
C'-----	52.88	.30	4.35	C'-----	73.25	2.71	2.05

Tables 21, 22 and 23 show the distribution by days for the recovery of test tags at the three ports. In the San Francisco region recovered tags were collected by the assistant wardens of the Bureau of Patrol. These men worked at the plants each day checking deliveries of fish, and made tag collections when free from other duties. Such collections were as a rule made every one to three days. At Monterey and San Pedro tags were collected by members of the laboratory staff and seldom was it possible to make the rounds of the plants more than once or, at the most, twice a week. Thus several days might have elapsed between the recovery of tags on a magnet and the collections of these tags from the plant.

Due to this lack of daily tag collection the data of tables 21-23 have been grouped into five day intervals. These data indicate that at San Francisco approximately 95 per cent of the tags recovered are returned within five days. At Monterey only about 70 per cent are returned

TABLE 19
Difference Between the Resulting Values for Port Efficiency for 1938-39 at Monterey as Calculated by Various Methods

Method	SMALL TAGS					Method	LARGE TAGS				
	A	A'	B	B'	C		A	A'	B	B'	C
	Value	75.14	71.86	74.32	72.86	74.26	Value	77.63	76.34	77.95	77.61
A'	71.86	3.28					76.34	1.29			
B	74.32	.82	2.46				77.95	.32	1.61		
B'	72.86	2.28	1.00	1.46			76.65	.98	.31	1.30	
C	74.26	.88	2.40	.06			77.61	.02	1.27	.34	.96
D	72.93	2.21	1.07	1.39	1.33		76.31	1.32	.03	1.64	1.30
Standard Error of Difference B-B', =.870.						Standard Error of Difference B-B', =.826.					

TABLE 20
Difference Between the Resulting Values for Port Efficiency for 1938-39 at San Pedro as Calculated by Various Methods

SMALL TAGS										LARGE TAGS						
Method	A	A'	B	B'	C	C'	D	Method	A	A'	B	B'	C	C'	D	
	Value	64.55	63.58	64.16	63.35	63.72	64.02		63.78	Value	69.15	68.65	69.80	69.81	69.63	71.61
A'	63.58	.97						A'	68.65	.50						
B	64.16	.39	.58					B	69.80	.65	1.15					
B'	63.35	1.20	.23	.81				B'	69.81	.66	1.16					
C	63.72	.83	.14	.44	.37			C	69.63	.48	.01	.18				
C'	64.02	.53	.44	.67	.30			C'	71.61	2.46	2.96	.17	1.80	1.98		
D	63.78	.77	.20	.38	.06	.24		D	69.93	.78	1.28	.13	.12	.30	1.68	
D'	62.93	1.62	.65	1.23	.42	1.09	.85	D'	70.71	1.56	2.06	.91	.90	1.08	.90	.78

Standard error of difference B-B' = 1.272.

Standard error of difference B-B' = 1.230.

TABLE 21

Length of Time Required to Recover Test Tags Placed in the
San Francisco Plants in 1938-39

Days	SMALL TAGS		LARGE TAGS	
	Number of tags recovered	Per cent recovered	Number of tags recovered	Per cent recovered
5	1,821	94.1	1,997	97.0
10	6	.3	28	1.4
15	21	1.1	7	.3
20	49	2.5	6	.3
25	16	.8		
30	14	.7	3	.1
35	1	.1	5	.2
40			5	.2
45				
50	2	.1		
55				
60	1	.1		
65	1	.1	2	.1
70			5	.2
75				
80				
85				
90			1	.1
95	3	.2		
100				
105				
110				
115	1	.1		
Totals	1,936	100.2	2,059	99.9

within five days and approximately 90 per cent within 10 days. The San Pedro results fall between those of the other two ports, with 78 to 9 per cent recovered within five days and 94 to 95 per cent within 10 days. The lower rate of recovery for the first five days at Monterey and San Pedro in contrast with San Francisco is probably explained by the less frequent collections at the first-named ports. At both Monterey and San Pedro, in a few instances, it was not possible to collect tags until more than five days after test tags had been placed in the plants. At such times all initial recoveries were assigned to the 6-10 day interval, whereas in all probability they had passed through the plant within the usual 1-5 day period. Since the method of collection of test tags was the same as those for live tags, this occasional failure to collect test tags within five days gives the desired measure of time interval for the recovery of live tags. Thus the distributions in tables 21-23 indicate that under present methods of tag recovery 70 to 95 per cent of the recovered tags will be returned within 5 days after they have entered the plant and 90 to 95 per cent within 10 days. The remaining 5 per cent represents the laggard tags which have "hung up" in the plant machinery and which may be recovered any time over an interval of 100 to 200 or more days. Some will not be returned until the following season. There appear to be no significant differences between the time required for the recovery of large and small tags.

Similar tests of efficiency of tag recovery have been reported by Hart, 1938, for British Columbia processing plants, and by Shuman, 1939, for Washington. Hart records a recovery of 92 per cent within

TABLE 22

Length of Time Required to Recover Test Tags Placed in the
Monterey Plants in 1938-39

Days	SMALL TAGS		LARGE TAGS	
	Number of tags recovered	Per cent recovered	Number of tags recovered	Per cent recovered
1- 5	5,083	69.6	5,453	70.8
6- 10	1,391	19.0	1,564	20.3
11- 15	259	3.5	261	3.4
16- 20	205	2.8	147	1.9
21- 25	98	1.3	85	1.1
26- 30	47	.6	49	.6
31- 35	52	.7	42	.5
36- 40	51	.7	35	.5
41- 45	26	.4	15	.2
46- 50	25	.3	16	.2
51- 55	5	.1	3	.0
56- 60	16	.2	10	.1
61- 65	21	.3	11	.1
66- 70	1	.0	3	.0
71- 75	3	.0	3	.0
76- 80	12	.2	8	.1
81- 85	2	.0	1	.0
86- 90				
91- 95	4	.1		
96-100				
101-105	3	.0		
106-110				
111-115				
116-120	1	.0	1	.0
121-125				
126-130	1	.0		
161-165	1	.0		
266-270	1	.0		
Totals	7,308*	99.8	7,707	99.8

* This total is less by two than the total number of small tags recovered as given in Table 4. The date of recovery was not recorded for these two tags, hence they could not be included in these calculations.

5 days and of 99 per cent within 10 days. Shuman gives records for individual plants but makes no summations. From Shuman's tables the records for Washington (omitting the second test for the John Doe plant) have been summed by the same method as used for California tests. This summation indicates a recovery for Washington plants of 96 per cent within 5 days and 99 per cent within 10 days. Both British Columbia and Washington tests give a somewhat more rapid recovery of tags than do the California tests and a smaller percentage of laggards. The maximum time of recovery is 45 days for British Columbia plants and 20 days for Washington.

TAGS RECOVERED IN THE SUCCEEDING SEASONS

When analyzing results of live tag recoveries, an occasional tag is found which is definitely known to have entered a plant the previous season and held over until the following season. Other tags are recovered which are subject to question. They may be "hold-overs" or they may not. The test tags of the 1938-39 season give us a measure of the percentage of error which may enter into our calculations due to misassigning hold-overs.

TABLE 23

Length of Time Required to Recover Test Tags Placed in the
San Pedro Plants in 1938-39

Days	SMALL TAGS		LARGE TAGS	
	Number of tags recovered	Per cent recovered	Number of tags recovered	Per cent recovered
5	2,559	78.4	2,771	79.4
10	522	16.0	547	15.7
15	80	2.5	67	1.9
20	21	.6	24	.7
25	43	1.3	43	1.2
30	11	.3	11	.3
35	5	.2	2	.1
40	5	.2	6	.2
45	8	.2	4	.1
50	1	.0	2	.1
55	1	.0	2	.1
60			1	.0
65	2	.1	3	.1
70	1	.0	1	.0
75	2	.1	1	.0
80	1	.0		
85			1	.0
90				
95	1	.0	3	.1
100	1	.0		
105				
110				
115	1	.0		
120			1	.0
Totals	3,265	99.9	3,490	100.0

TABLE 24

Proportion of Test Tags Put Into the San Francisco Plants in 1938-39
and Recovered in 1939-40

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered		Per cent* hold-overs	Number of tags used	Number of tags recovered		Per cent* hold-overs
		1938-39	1939-40			1938-39	1939-40	
	199	171	0	.00				
					100	78	0	.00
					200	168	0	.00
	199	37	1	.50				
	596	484	0	.00	296	270	0	.00
	397	218	0	.00	300	208	0	.00
	399	203	0	.00	300	256	0	.00
	197	149	1	.51	100	86	0	.00
	100	41	0	.00	298	117	0	.00
	99	42	1	1.01	100	67	0	.00
	300	190	0	.00	199	165	0	.00
	100	73	0	.00	400	308	0	.00
	299	85	0	.00	199	76	0	.00
	300	115	8	2.67	300	175	7	2.33
	198	128	0	.00	100	85	0	.00
Totals	3,383	1,936	11	0.33	2,892	2,059	7	0.24

* This is a percentage of the number of tags used, not of the number of tags recovered.

TABLE 25
Proportion of Test Tags Put Into the Monterey Plants in 1938-39 and Recovered in 1939-40

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered		Per cent* hold-overs	Number of tags used	Number of tags recovered		Per cent* hold-overs
		1938-39	1939-40			1938-39	1939-40	
1.....	792	287	0	.00	798	381	0	.00
2.....	939	634	0	.00	947	685	2	.21
3.....	944	812	0	.00	931	828	0	.00
4.....	831	685	1	.12	845	757	1	.12
5.....	935	814	4	.43	942	858	2	.21
6.....	1,531	1,286	1	.07	1,538	1,342	0	.00
7.....	744	554	6	.81	745	604	11	1.48
8.....	1,340	1,066	11	.82	1,345	1,043	2	.15
9.....	939	671	1	.11	948	642	0	.00
10.....	841	521	0	.00	848	567	0	.00
Totals.....	9,836	7,310	24	.24	9,887	7,707	18	.18

* This is a percentage of the total number of tags used, not of the number of tags recovered.

TABLE 26
Proportion of Test Tags Put Into the San Pedro Plants in 1938-39 and Recovered in 1939-40

Plant ²	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered		Per cent ¹ hold-overs	Number of tags used	Number of tags recovered		Per cent ¹ hold-overs
		1938-39	1939-40			1938-39	1939-40	
1.....	764	613	16	2.09	783	669	23	2.94
3.....	596	437	0	.00	598	464	0	.00
4.....	593	292	2	.34	587	344	2	.34
5.....	599	435	1	.17	498	370	3	.60
6.....	749	372	0	.00	744	388	0	.00
7.....	399	243	0	.00	396	266	0	.00
8.....	694	505	7	1.01	696	594	2	.29
Totals.....	4,394	2,897	26	.59	4,302	3,095	30	.70

¹ This is a percentage of the total number of tags used, not of the number of tags recovered.

² The magnet in plant 2 was removed previous to the opening of the 1939-40 season hence no tags were recovered from this plant during 1939-40.

In tables 24, 25, and 26 are shown for the three ports the number of test tags used at each plant, the number recovered in 1938-39, the number recovered in 1939-40 and the percentage recovered in 1939-40 in terms of the total number of test tags used. The lowest percentage of hold-overs occurs at Monterey and the highest at San Pedro, but in no locality does it reach 1 per cent for the entire port. For one plant at San Francisco and one at San Pedro the percentage is between two and three. For all other plants it is one or less. Thus in general one per cent or less of tags entering plants will be held over until the following season. If the calculations were made on the basis of the number of tags recovered, the percentage of hold-overs would be slightly higher but still would not equal one per cent at any port. Thus we can conclude that hold-over tags do not cause an error greater than 1 per cent in our records of live tag recoveries.

During the 1940-41 season, from the 1938-39 tests, one large tag was recovered at San Francisco, 6 small and 4 large at Monterey, and one large tag at San Pedro. Hold-overs can and do carry over to the second season after tagging but such tags constitute less than .1 per cent of the tags which enter the plants or of tags which are recovered from the plants.

RELATION BETWEEN RECOVERIES FROM THE REDUCTION OF CANNING OFFAL AND FROM THE REDUCTION OF WHOLE FISH

At the onset of the investigation it seemed evident that fewer tags would be recovered on the magnets when sardines were canned and only the offal reduced than would be recovered when whole fish were run through the reduction plant. This difference would supposedly result from the fact that an unknown proportion of tags would be lost from the offal between the canning line and the reduction pit. Any experimental test of this loss, however, would not have duplicated the conditions of live tags. Tags placed in live fish become encysted within the body cavity (See "Effect of internal tags upon sardines") and thus will have a greater chance of clinging to the offal and being carried to the reduction

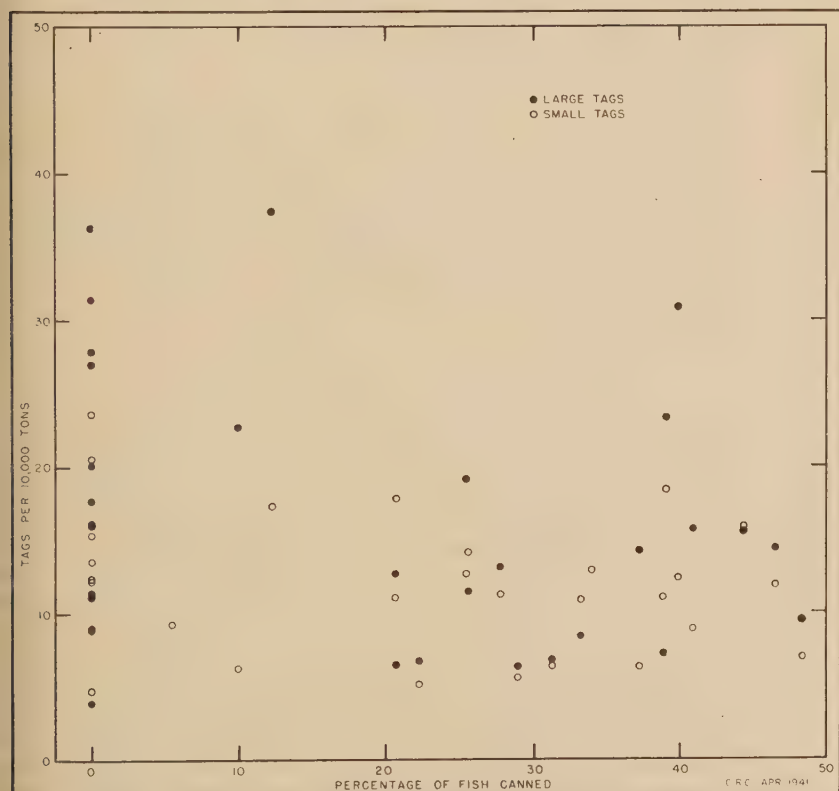


FIG. 2. Relation between the number of tags recovered per 10,000 tons and the proportion of fish canned at each plant where magnets were installed at San Francisco, Monterey and San Pedro in 1938-39.

pit than will test tags placed in dead fish before they passed through the canning line.

If, however, this difference in the chance of recovery of tags from canned fish and from whole fish is valid it should be evident in the number of tags recovered per ton from sardines handled by the two methods. This has been calculated for the 1938-39 season for each of the plants in the three ports where magnets were installed. The number of live tags recovered was weighted to the theoretical total which would have been recovered had recovery methods in the reduction plant been 100 per cent efficient. In figure 2 the number of small and large tags per 10,000 tons is plotted against the percentage of fish canned, for each plant in the three ports. The data are given for each port in table 27. It is evident that there is no tendency for fewer tags to be recovered from plants canning a fair percentage of sardines than from plants which put all or the major portion of their sardines into whole fish reduction.

TABLE 27

Relation Between Percentage of Fish Canned and Number of Tags Recovered in the 1938-39 Season

SAN FRANCISCO				MONTEREY				SAN PEDRO			
Plant	Per cent canned	Tags per 10,000 tons		Plant	Per cent canned	Tags per 10,000 tons		Plant	Per cent canned	Tags per 10,000 tons	
		Small	Large			Small	Large			Small	Large
1	5.43	9.30		1	28.94	5.50	6.26	1	39.01	18.47	23.35
2	0.00		3.88	2	40.88	8.81	15.54	2	46.49	11.79	14.43
3	0.00		8.89	3	25.51	14.15	11.40	3	12.14	17.30	37.36
4	33.96	12.85		4	31.23	6.26	6.91	4	20.65	17.81	6.41
5	0.00	11.41	27.94	5	22.29	5.05	6.63	5	44.43	15.82	15.47
6	0.00	11.26	20.08	6	20.55	11.01	12.63	6	39.88	12.32	30.79
7	33.22	10.90	8.36	7	0.00	13.53	15.98	7	25.42	12.68	19.14
8	0.00	20.51	27.05	8	27.67	11.23	13.09	8	48.45	6.85	9.49
9	9.97	6.23	22.75	9	37.08	6.24	14.26				
10	0.00	15.28	31.43	10	38.83	11.01	7.14				
11	0.00	12.12	11.11								
12	0.00	12.42	17.66								
13	0.00		16.07								
14	0.00	23.60	36.19								
15	0.00	4.73	9.00								

The data were also broken down by ports and by individual months within the season. All methods of treating the data produced the same results, i.e., no tendency for fewer tags to be recovered from canned fish. At San Pedro for the month of December there occurred the only group of data which showed a slight tendency for more tags to be recovered from the reduction of whole fish. The value of the correlation coefficient, r , for this month's data was $-.63$ which did not prove to be statistically significant.

The tag returns at all ports for the 1939-40 season were submitted to the same comparisons and also showed no indications of a greater recovery of tags from the reduction of whole fish than from the reduction of offal from canned fish. The conclusion seems justified, therefore, that under present methods of canning in California, the recovery of tags from canned offal is as effective as the recovery from the reduction of whole fish. Any differences which may exist are too small to be measured from the data at hand.

TABLE 28

Calculations of Port Efficiency for 1939-40 for the Recovery of Tags at San Francisco by Method A'

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
1.....	96.00	3	3.12	84.00	11	13.10
2.....	65.31	4	6.12	90.00	9	10.00
3.....	50.00	9	18.00	65.31	7	10.72
4.....	30.65	2	6.53	40.10	15	37.41
5.....	91.28	1	1.10	90.21	11	12.19
6.....	61.74	2	3.24	58.39	14	23.98
7.....	60.14	10	16.63	81.21	21	25.86
8.....	91.00	5	5.49	96.00	6	6.25
9.....	45.00	3	6.67	52.00	2	3.85
10.....	63.00	4	6.35	71.72	12	16.73
11.....	69.33	5	7.21	75.17	11	14.63
12.....	63.19	4	6.33	69.33	8	11.54
13.....	16.00	1	6.25	16.67	3	18.00
14.....	19.86	1	5.04	20.41	3	14.70
15.....	81.00	5	6.17	85.86	8	9.32
17.....	42.00	2	4.76	52.35	10	19.10
18.....	94.95	10	10.53	97.96	12	12.25
19.....	55.10	2	3.63	70.41	14	19.88
20.....	80.81	1	1.24	73.00	4	5.48
21.....	1.00	0		4.04	0	
Totals.....		74	124.41		181	284.99
Port efficiency.....	$\frac{74 \times 100}{124.41} = 59.48\%$			$\frac{181 \times 100}{284.99} = 63.51\%$		

TABLE 29

Calculations of Port Efficiency for 1939-40 for the Recovery of Tags at Monterey by Method A'

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
1.....	24.50	3	12.24	25.50	10	39.22
2.....	77.00	18	23.38	80.50	59	73.29
3.....	86.50	10	11.56	95.48	25	26.18
4.....	57.50	11	19.13	65.33	10	15.31
5.....	74.87	6	8.01	86.43	28	32.40
6.....	66.33	18	27.14	70.50	33	46.81
7.....	71.14	5	7.03	78.52	15	19.10
8.....	62.31	16	25.68	73.43	48	65.37
9.....	57.00	4	7.02	59.30	16	26.98
10.....	34.17	5	14.63	32.16	14	43.53
Totals.....		96	155.82		258	388.19
Port efficiency.....	$\frac{96 \times 100}{155.82} = 61.61\%$			$\frac{258 \times 100}{388.19} = 66.46\%$		

TABLE 30

Calculations of Port Efficiency for 1939-40 for the Recovery of Tags at San Pedro by Method A'

Plant	SMALL TAGS			LARGE TAGS		
	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered	Per cent of test tags recovered	Number of live tags recovered	Theoretical number of live tags recovered
1.....	53.23	16	30.06	56.63	22	38.85
3.....	68.70	2	2.91	76.61	14	18.27
4.....	90.00	4	4.44	96.64	3	3.10
5.....	84.34	30	35.57	90.20	1	1.11
6.....	62.10	32	51.53	65.59	6	9.15
7.....	44.67	8	17.91	55.00	3	5.45
8.....	88.38	9	10.18	94.50	8	8.47
9.....	87.07	3	3.45	90.54	2	2.21
10.....	42.00	0		72.00	1	1.39
Totals.....		104	156.05		60	88.00
Port efficiency.....	$\frac{104 \times 100}{156.05} = 66.65\%$			$\frac{60 \times 100}{88.00} = 68.18\%$		

TABLE 31

Calculations of Port Efficiency for 1939-40 for the Recovery of Tags at San Francisco by Method B'

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent of tags recovered	Standard error	Number of tags used	Number of tags recovered	Per cent of tags recovered	Standard error
1.....	50	48	96.00		50	42	84.00	
2.....	49	32	65.31		50	45	90.00	
3.....	50	25	50.00		49	32	65.31	
4.....	199	61	30.65		197	79	40.10	
5.....	149	136	91.28		143	129	90.21	
6.....	149	92	61.74		149	87	58.39	
7.....	148	89	60.14		149	121	81.21	
8.....	100	91	91.00		100	96	96.00	
9.....	100	45	45.00		100	52	52.00	
10.....	100	63	63.00		99	71	71.72	
11.....	150	104	69.33		149	112	75.17	
12.....	144	91	63.19		150	104	69.33	
13.....	150	24	16.00		150	25	16.67	
14.....	146	29	19.86		147	30	20.41	
15.....	100	81	81.00		99	85	85.86	
17.....	150	63	42.00		149	78	52.35	
18.....	99	94	94.95		98	96	97.96	
19.....	98	54	55.10		98	69	70.41	
20.....	99	80	80.81		100	73	73.00	
21.....	100	1	1.00		99	4	4.04	
Totals.....	2,330	1,303	55.92	±1.03	2,325	1,430	61.51	±1.01

CALCULATIONS OF PORT EFFICIENCY FOR THE 1939-40 SEASON

During the 1939-40 sardine season monthly tests were made of the efficiency of tag recoveries in each of the three ports, San Francisco, Monterey and San Pedro. From these tests port efficiencies have been calculated by methods A' and B'. The calculations are shown in tables 28-33, and compared with the 1938-39 port efficiencies in table 17. At San Francisco for large tags and at Monterey for both large and small tags the efficiency values were about 10 units less in 1939-40 than in the previous season. For small tags at San Francisco, method A' gave a higher efficiency in 1939-40 and B' gave a lower value. At San Pedro for both sizes of tags the port efficiency was somewhat higher in value in 1939-40 with the exception of the results for large tags by Method A'. This showed a slight decrease.

TABLE 32

Calculations of Port Efficiency for 1939-40 for the Recovery of Tags at
Monterey by Method B'

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent recovered	Standard error	Number of tags used	Number of tags recovered	Per cent recovered	Standard error
1-----	200	49	24.50		200	51	25.50	
2-----	200	154	77.00		200	161	80.50	
3-----	200	173	86.50		199	190	95.48	
4-----	200	115	57.50		199	130	65.33	
5-----	199	149	74.87		199	172	86.43	
6-----	199	132	66.33		200	141	70.50	
7-----	149	106	71.14		149	117	78.52	
8-----	398	284	71.36		399	293	73.43	
9-----	200	114	57.00		199	118	59.30	
10-----	199	68	34.17		199	64	32.16	
Totals----	2,144	1,344	62.69	±1.04	2,143	1,437	67.06	±1.02

TABLE 33

Calculations of Port Efficiency for 1939-40 for the Recovery of Tags at
San Pedro by Method B'

Plant	SMALL TAGS				LARGE TAGS			
	Number of tags used	Number of tags recovered	Per cent recovered	Standard error	Number of tags used	Number of tags recovered	Per cent recovered	Standard error
1-----	248	132	53.23		249	141	56.63	
3-----	246	169	68.70		248	190	76.61	
4-----	150	135	90.00		149	144	96.64	
5-----	249	210	84.34		245	221	90.20	
6-----	248	154	62.10		247	162	65.59	
7-----	197	88	44.67		200	110	55.00	
8-----	198	175	88.38		200	189	94.50	
9-----	147	128	87.07		148	134	90.54	
10-----	50	21	42.00		50	36	72.00	
Totals----	1,733	1,212	69.94	±1.10	1,736	1,327	76.44	±1.02

TABLE 34

Differences Between the Resulting Values of Port Efficiency for 1939-40
as Calculated by Methods A' and B'

Method	SMALL TAGS			LARGE TAGS		
	A'	B'	Difference	A'	B'	Difference
San Francisco.....	59.48	55.92	3.56	63.51	61.51	2.00
Monterey.....	61.61	62.69	1.08	66.46	67.06	.60
San Pedro.....	66.65	69.94	3.29	68.18	76.44	8.26

In table 34 are shown the differences between port efficiencies for 1939-40 as derived by methods A' and B'. As in the comparisons between methods for the 1938-39 season, those for 1939-40 do not show significant differences at San Francisco and Monterey nor for small tags at San Pedro. For the San Pedro tests on large tags the difference between the A' and B' methods is 8.26 and perhaps statistically significant. As pointed out above, the standard error of 68.18 per cent (the port efficiency derived from method A') cannot be calculated because the data for measuring the chances of recovery of live tags is lacking and the number of live tags recovered enters into the calculations by method A'.

If the difference is considered significant the results can be interpreted as an indication that live tags were not equally available to all fishermen in the San Pedro region in 1939-40, and method A' should be used for calculating port efficiency. Since, however, this large difference occurred in only one out of the six comparisons for 1939-40, its statistical significance may be questioned and the result interpreted as a chance variation due to random sampling. This argument is further strengthened by the comparison of methods A and B for 1938-39 which showed no significant differences. Assuming that live tags are equally available throughout the fishing grounds, method B is more satisfactory for the calculation of port efficiency because of its greater simplicity and because it involves the sampling errors of test tags only and not those of live tags.

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